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International Development Research Centre

MANUSCRIPT REPORT

Bean Network

Proceedings of the First Workshop held at the University of Guelph, Guelph, Canada, 26–29 June 1985

December 1985

CANADA

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This series includes meeting documents, internal reports, and preliminary technical documents that may later form the basis of a formal publication. A Manuscript Report is given a small distribution to a highly specialized audience.

La présente série est réservée aux documents issus de colloques, aux rapports internes et aux documents techniques susceptibles d'être publiés plus tard dans une série de publications plus soignées. D'un tirage restreint, le rapport manuscrit est destiné à un public très spécialisé.

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26-29 June 1985

Editors: W. Edwardson, A. Fisher, and A.McNaughton

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II INTRODUCTION

IDRC

The International Development Research Centre is an organization that supports research designed to yield knowledge and information that can contribute to Third World development. Within the Centre, the Cooperative Program has been created to promote research collaboration between groups in Canada and those in the developing world, in the execution of projects that address a problem identified in the Third World. In addition to this thrust, the program has three other important objectives:

- To develop the scientific and technological research capacity of the participating Third World institutions or groups by improving their opportunities for collaboration with the Canadian part of the international scientific community;

- To create channels of communication among scientists through which the results of successful research in Canada can be transferred to researchers in the Third World (the even more difficult transfer -- from scientist to user -- can then be addressed in the context of the developing country involved, as a separate step); and

- To influence the direction of Canadian research toward Third World concerns.

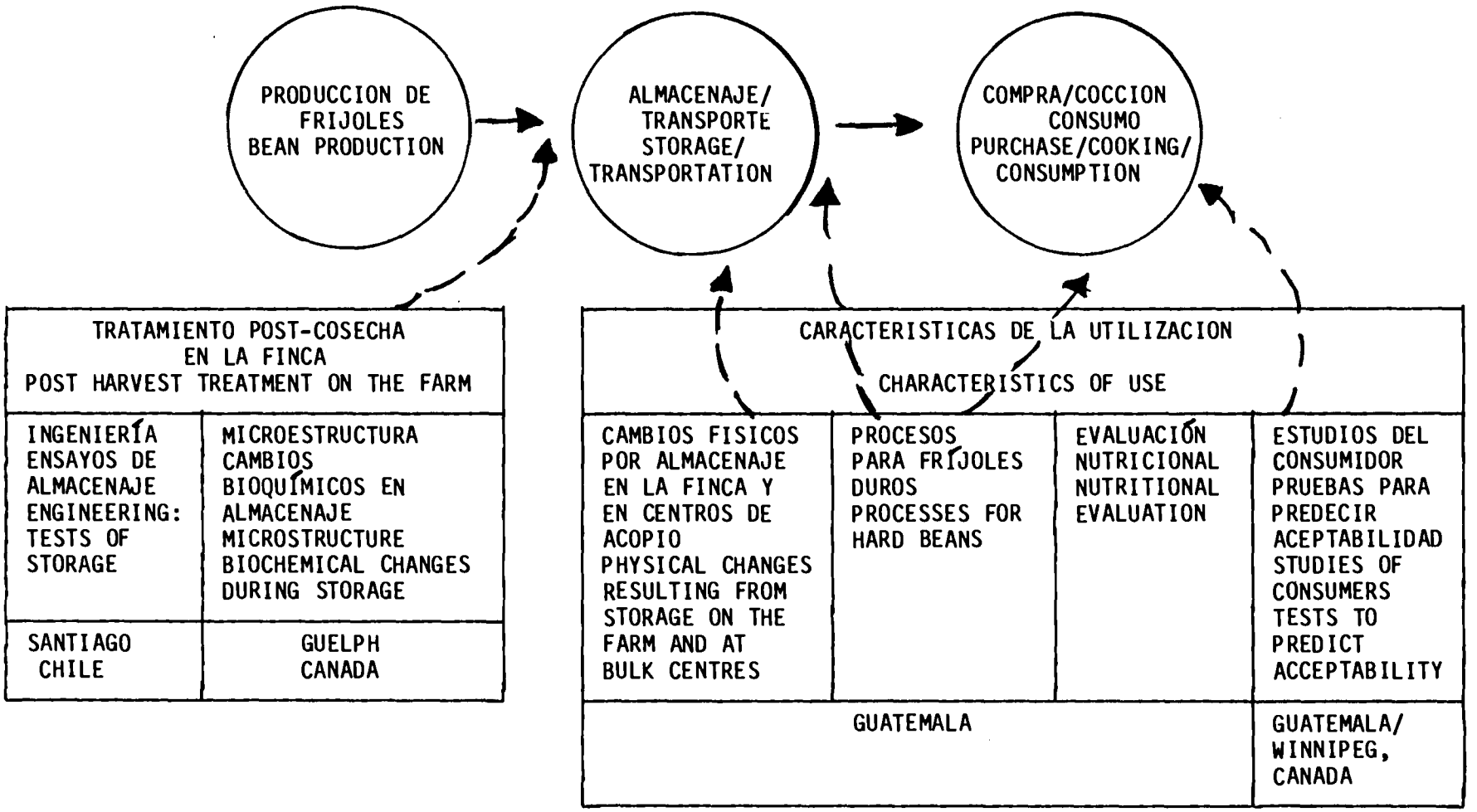
The Problem

Worldwide production of food legumes is over 50 million tonnes of which more than half are produced in developing countries where they supplement cereal diets with essential amino acids. IDRC has supported research on legume quality in several countries including faba beans in Egypt, lentils in Lebanon and common beans in Guatemala. Researchers have tried to overcome the hardness and hard-to-cook properties which develop during storage and which cause economic loss through decreasing consumer acceptability and energy loss through increased fuel consumption.

Past work has sought correlations between mineral, protein or starch content, seed components (hull, cotyledon) and the degree of hardness after various conditions of storage. Various indices of hardness, usually of cooked beans have been examined. Still required is a fundamental understanding of the mechanisms involved, standardization of bean samples, of handling and cooking procedures and of hardness testing both by physical instruments and human senses.

The study of common beans (Phaseolus vulgaris) is being conducted by a network of specialized research activities aimed at increasing the consumption and nutritive quality of dried beans. The network consists of two project teams. The Catholic University of Chile and the University of Guelph, Canada are working together to devise technologies, accessible to small Chilean producers, for inhibiting the development of the hard-to-cook property in stored, dried Phaseolus beans. The Instituto de Nutricion para Centro America y Panama (INCAP), Guatemala and the University of Manitoba, Canada are working jointly to develop consumer acceptability criteria for beans in Guatemala, for use in research programs aimed at increasing bean availability and consumption, and to increase the utilization and nutritive value of beans through improved small scale industrial processing.

FIGURA 1. PROYECTOS DE INVESTIGACION EN FRIJOLES
FIGURE 1. RESEARCH PROJECTS IN BEANS



In 1983, IDRC received a request from the Catholic University of Chile for support for a joint project with the University of Guelph to develop post-harvest processing of beans for on-farm use in Chile. The research specifically proposed to reduce the hardening of beans associated with prolonged storage. Chile is an exporter of black beans, the major market being the countries of Central America.

IRDC, which has previously supported other projects on hardening of food legumes, invited INCAP, Guatemala and researchers from the University of Manitoba, Canada to help with other aspects of the problems posed by hard-to-cook beans. The research network was formed to take advantage of the modern equipment available in Canadian universities to tackle the mechanisms involved in hardening and to standardize measurement of the phenomenon, while the institutions in Guatemala and Chile would concentrate on developing technologies for use in those countries and assess the concerns of their consumers and producers.

This co-operative approach is designed to consider all issues involved in the post-harvest production system and toward this end a network of four institutions, working on two parallel co-operative projects, was formed. The joint activity of all those concerned should speed the setting of priorities and the assessment of the validity of the questions being asked.

The Meeting

The purpose of this meeting was to permit the individual teams to report on their problems and achievements, to share priority setting and planning across the network. This was an opportunity to bring each other up-to-date on their activities, to seek ways to improve the interaction between network members and to ensure that compatible methods were being used toward the common goal of maximizing the availability of beans as a food resource. Research workers from Costa Rica and Brazil, although not part of the network, presented experiences in bean storage and hardness research from their countries and contributed effectively to discussions.

The Projects

The specific objectives of the two sets of projects are:

Guelph/Chile

1) to determine the biological changes that contribute to hardness during storage

2) to develop simple and inexpensive post-harvest roasting technologies to arrest hardening of beans, improve their keeping quality and reduce cooking time

3) to determine optimal storage conditions for different dry beans

INCAP/Manitoba

1) to define specific characteristics of bean acceptability, using consumer survey techniques

2) to establish a uniform, reliable laboratory methodology to quantify the physical, chemical, and sensory characteristics of bean quality as defined by Guatemalan consumers; correlate the laboratory methods with consumer panel data; and identify the number of tests needed to define consumer acceptability

3) to evaluate hardness development in bulk storage and under farm conditions

4) to develop procedures for the utilization of hard-to-cook beans in local foods

5) to evaluate the effect of processing methods on protein digestibility and nutritive value.

MAJOR CONCLUSIONS

(1) Generally all projects were on schedule in terms of activities.

(2) There existed some differences in methodology particularly with regard to bean hardness measurement and expression of results. All teams agreed to provide detailed methodologies and to record at least force measurements when using texturometers. The arrival of the OTMS system at INCAP will permit the integration of their measurements into the network.

(3) Opportunities were identified for interaction among all four groups in their research activities, not restricted to the paired team collaboration currently in the project structure. Plans were made particularly for provision of Chilean bean samples from the next harvest, to all three other centres in the network.

(4) The need for timely and informed co-ordination of all activities was emphasized, particularly as the intensity and complexity of research is increasing rapidly with some twenty-eight researchers in the network (including students). For the moment, a quarterly news sharing service will be implemented, but a network co-ordinator will be required if a second phase is warranted.

(5) The next meeting will be held in Guatemala to allow the attendance of the full Latin teams and to provide opportunities for field visits to view problems first-hand. The tentative date is the last week of May. IDRC/INCAP will be in charge of arrangements.

III PROGRESS - GUELPH/CHILE PROJECTS

José Miguel Aguilera, Project Leader, Catholic University, Chile

Chile produces beans in excess of domestic demand -- about 50 percent of the total crop is exported. Black beans, along with some other varieties are not commonly consumed in Chile but are grown for export, chiefly to countries of Central America.

The Chilean research team is concentrating on engineering aspects to overcome the hard-to-cook problem in beans. They have developed mathematical models to describe and predict rates of hardening under various storage conditions. Relative hardness is measured as the ratio of bean hardness after storage to bean hardness prior to storage. Research indicates that hardening can be delayed when beans are stored at 25°C by reducing the moisture content of the beans (see Appendix 1, page 49).

Roasting by solid-to solid heat transfer was found to be an effective non-chemical method of treating insect-infested beans. Roasting was also found to retard hardening if the moisture content of the beans is kept low during storage. In addition, it lowered moisture content one or two percent below the 10.5 percent achieved by sun-drying.

Discussion

The possibility that the delay of hardening attributed to the roasting treatment could be influenced by a decrease in the initial (pre-storage) moisture content was discussed. The effect of roasting appears to be independent of its effect on initial moisture since the moisture of the roasted and non-roasted beans were equilibrated to different moisture conditions prior to storage.

It was suggested that roasting could increase breakage of the seed coat. Although this does not appear to be a serious problem, the team is currently assessing it quantitatively.

In an effort to discriminate between enzymatic and non-enzymatic processes, samples are being treated by microwave and radiation prior to storage. For more details see page 49.

Dave Stanley, Project Leader, University of Guelph, Canada

The Guelph team's participation in this project began in January of 1984. Their role is to investigate the mechanisms that cause the hard-to-cook defect in black beans. Although the partial mechanisms have been identified, there is still much research needed to complete the picture. Co-operation with the Chilean research team allows an understanding of the applied part of the problem and, as the mechanism involved is uncovered, help with the empirical aspects will be possible. Together, the research is both practical and basic.

Work started with preparation and a review of the literature which has now been accepted for publication by the Journal of Food Biochemistry and the Journal of Food Processing and Preservation. In addition, Canadian Research has published a paper prepared by IDRC outlining the processes involved in the Guelph-Chile project (Appendix I, pages 76, 124 and 186 respectively).

Michael Hincks, University of Guelph, Canada

In this study of the mechanisms involved in the hard-to-cook defect in black beans, only samples of Chilean beans that were untreated prior to storage and those that were roasted at 150°C for two minutes were used. Similarly, while the Chilean team is considering storage effects under a range of conditions, Hincks is studying only the extremes of high temperature and high humidity (30°C, 85%RH) and low temperature and low humidity (15°C, 35%RH).

Earlier research suggested that phytase activity was responsible for hardening but this is now thought to be only a contributing factor and not solely responsible. Since pre-storage roasting seems to be effective only if the beans are subsequently stored at low moisture, non-enzymatic processes seem to be partially responsible.

Because lignification can proceed either enzymatically or non-enzymatically, it is one of the mechanisms that may explain why roasting the beans fails to arrest the hardening process. Scanning electron microscopy shows that the cotyledon cells of beans stored under conditions of high temperature and high humidity remain tightly packed together while the cells of beans stored at low temperature and low humidity separate when cooked (see pages 69-70). This implicates the cell wall-middle lamella complex as the site of the hard-to-cook phenomenon. Lignification may affect this complex, making the cell wall less permeable to water and reducing hydration of cell components, which in turn may affect the gelatinization of starch and denaturation of protein.

Interference microscopy shows a regular crystalline structure in the seed hull. The possibility that these structures may be calcium oxalate resulting from mineralization and could be associated with the "hulliness" or "graininess" in cooked beans was discussed. Aguilera will be examining these structures with an electron microscope while visiting Guelph.

Andres Hohlberg, University of Guelph, Canada

Intracellular starch and protein of the bean cotyledon are being studied to assess their non-enzymatic contribution to hardening. Specifically, experiments are proposed to investigate whether amylose or peptides are leaching into the middle lamella and catalyzing polymerization reactions. Isolates of starch and protein will be compared to in vitro starch and protein to assess whether the results obtained with isolates can be extrapolated to whole beans.

Starch is separated by the wet method, homogenized and centrifuged. Protein bodies are physically separated by dry screening and centrifuging in glycerol. Proteins are extracted with NaCl, filtration and dialysis.

Although Hincks is using samples stored only at the extremes of temperature and relative humidity, a third set of samples stored at 25°C and 65%RH is being used in this investigation. Research reported from Brazil indicates that beans stored under these conditions developed "hard shell" and this will be investigated. This third storage environment will also more closely resemble ambient conditions in Chile than the other storage parameters being studied.

Leslie Plhak, University of Guelph, Canada

Enzymatic processes related to post-harvest hardening of black beans are being studied. Specifically, samples are being tested monthly for phytase activity, perodixase activity, phenols and lignins.

Samples of Chilean beans have undergone the following pre-storage treatments:

1) sun dried out of the pod at less than 39°C
2) solar dried, 75-80°C
3) irradiated, one megarad (expected to damage enzymes)
4) microwave 75-80°C
5) sun dried in pods (traditional method in Chile)
   a) grown without added phosphorus
   b) grown with added phosphorus
6) roasted at 80°C for two minutes

Each of these samples will be further subdivided by storage at

1) 30°C and 85%RH
2) 15°C and 35%RH

Since this research was only initiated in mid-May, no conclusive results are reported. The attempt to study changes over time after harvest are reported. Since samples harvested in February arrived in Guelph only in May, effects of storage from time zero cannot be studied.

Jeff Smith, University of Guelph, Canada

Non-enzymatic, post-harvest processes in asparagus are being studied as a possible model for lignification. Asparagus were chosen because non-enzymatic changes occur rapidly after harvest, whereas beans require several months to develop hardness.

Peroxidase and polyphenyloxidase are thought to indicate lignification. Smith, therefore studied the effect of blanching on changes in percent fibre, texture, peroxidase, and polyphenyloxidase over time and at different temperatures of storage. Initial tests showed no lignification in either blanched or unblanched samples but this may simply be because the asparagus rotted before lignification could proceed. Further experimentation with frozen asparagus may lead to more conclusive results.

Summary

Since heat treatment will inhibit only part of the hardening in black beans the phenomenon seems to be a least partly non-enzymatic.

The cell walls and middle lamella appear to be target areas for the hardening process.

If water is being absorbed by hard-to-cook beans during cooking, but is not causing softening, the region of water activity may be important. Is the absorbed water intra or extracellular in hard-to-cook beans?

The Chilean team found that hardening was eventually arrested in beans stored in sealed polyethelene bags. If this is caused by changes in the storage atmosphere related to respiration, controlled atmosphere storage may prove to be effective.

Studies with isolates shows promise of clarifying the roles of starch and protein breakdown in the hardening process.

Research efforts are now focussed on clarifying the contribution of phenols and enzymatic products to the process of lignification.

Discussion

Heat treatment is not totally ineffective; it does cause a lag in the hardening process as well as preventing infestation prior to storage. Results of the storage practices survey being done by INCAP and the acceptability tests will be used to assess whether the effect of heat treatment is sufficient.

If heat treatment is not sufficiently effective, the possibility of achieving low temperature, low humidity storage should be examined. Sartori suggested that relatively low temperatures can be maintained in underground polyethylene silos. In Brazil, underground storage was found to be effective in delaying hardening of beans at 12 percent moisture. Relatively low temperatures can be maintained only a few feet below the ground if the storage area supports a stand of tall grass.

Since beans stored at low moisture content seem to harden less quickly, it may be that drying (through roasting) and sealed storage could be combined to effectively reduce hardening.

Sartori reports that farmers in Brazil are not interested in drying beans because there is no economic incentive. The beans lose weight and the hardness of the raw beans is increased. Consumers judge beans by hardness when raw and so reject dried beans thinking them to be hard-to-cook. Although research has shown that dried beans are less hard-to-cook, extension workers find it difficult to convince farmers of the merits of drying beans more than is traditional.

In Brazil, researchers have concentrated on technologies that are suitable for large producers, co-operatives or government storage rather than individual small-hold farmers. Sartori suggests that small producers sell any surplus production immediately after harvest and store only for home consumption. Technological innovations are likely to be more economical for bulk storage than for individual stores of 200 to 400 kilograms.

IV PROGRESS, INCAP/UNIVERSITY OF MANITOBA PROJECT

1. Project planning
2. Focus group interviews
3. Survey design
4. Survey
5. Labortory tests - physical
   - chemical
   - sensory
6. Consumer acceptability validation
7. Establishment of "package" of tests applicable in different bean-consuming populations for determining the acceptability of new varieties of beans.

Luis Elias, Project Leader, INCAP, Guatemala

Although Central America suffers an estimated total annual loss of $40 million CAD from bean hardening, most studies, such as those by FAO, consider only physical losses and ignore the economic and nutritional losses resulting from the hard-to-cook phenomenon. The lack of data on the effect of hardness on consumer acceptability hampers the successful evaluation of new, high yielding or disease resistant varieties of beans.

Research at INCAP is aimed at increasing the availability and consumption of beans. The two main approaches are: 1) to develop methods to evaluate consumer acceptability and 2) to develop small-scale processing technologies to combat the losses incurred with hard beans.

This work includes -- development and implementation of a consumer survey to evaluate specific characteristics of acceptability.

-- development of a laboratory method of cooking that applies to consumer methods

-- evaluation of the development of hardness during bulk and on-farm storage

-- development of procedures to use hard-to-cook beans in local foods (industrial)

-- evaluation of the effect of processing on protein digestibility and nutrient content.

Three students are working on the following aspects:

1) new methods to cook beans
2) cooking time related to mineral content of beans
3) evaluation of losses during storage

Bev Watts, University of Manitoba, Canada

The Manitoba research team comes to this project with experience in "cookability" studies of Manitoba navy beans. As part of this research the Mattson cooker was calibrated using a trained sensory panel. The Mattson cooker is calibrated by adjusting the weight of the rod and the diameter of the plunger points. Research results indicate that 92 percent "doneness" (23 of 25 rods sunk) best correlates with data obtained by the sensory panel. In concurrence with preliminary data from Guatemala, the location at which the beans were grown seems to affect cooking time more than the variety grown. In both cases this seems to be related to the mineral content of the soils at each growing location. See pages 189-202 for the abstract of the thesis by J.R. Proctor, dealing with this topic, and figures representing the results in a graphical form. See page 276 for illustration of Mattson cooker as used by Sartori.

Lois Jeffery, University of Manitoba, Canada

Jeffery joined the project only in February, 1985. Her goal is to develop objective tests for quality of beans hardness, firmness and colour and broth colour and viscosity to determine factors which will affect consumer acceptability.

The literature has many examples of "hedonic" testing (preference only) which tends to be too subjective to yield predictive data. People in a trained sensory panel can be an accurate instrument but their judgments must be systematic and standardized. The techniques for quantifying texture evaluation are on pages 203-206.

An important textural feature that affects preference is skin toughness. In Guatemala "cascarudo" refers specifically to beans that are soft and fully cooked but are tough skinned or "hully".

Future plans include the development of tests to quantify flavour of cooked beans and broth.

Ruth Diamant, University of Manitoba, Canada

This project has been very much of a co-operative effort between INCAP and the University of Manitoba. The team of people from these institutions have jointly planned all aspects of the project, beginning with the visit by three of us from the University of Manitoba to INCAP in Guatemala in June of 1984.

GENERAL OBJECTIVE:

To develop methods for the assessment of consumer acceptability of beans in Guatemala for use as criteria in research programs aimed at increasing the availability and consumption of beans.

SPECIFIC OBJECTIVES:

1. To define the specific characteristics of bean acceptability by using consumer survey techniques.

2. To establish at the laboratory level a uniform, reliable and adequate methodology to quantitate the physical, chemical and sensory characteristics of bean quality as defined by the consumer; and to validate these laboratory methods using consumer panels; and to identify the minimum number of tests which define consumer acceptability.

3. To test these methods for evaluating characteristics of beans from a variety of locations and new varieties from national and international programs.

4. To develop the human resources for international co-operation in applied research in food and nutrition.

Focus Group Interviews

The first stage of the work used the pre-survey technique of focus interviews to obtain general information on consumer criteria for acceptability of black beans in Guatemala and on consumer practices in storing and cooking them. The objectives of the focus group interviews were:

1) to define the criteria used in the selection of black beans and the characteristics of good eating quality

2) to provide information on the storage and cooking metods used in Guatemalan homes

The focus group interview technique

-- provides a basis for items to be investigated in the survey
-- gives an indication of the scope of the questionnaire
-- shows consumer understanding of and concern with the problems
-- suggests hypotheses
-- gives the consumer's vocabulary and forms of expressions
-- yields soft data.

Observational procedures were also used in the kitchens of some of the interviewees to find out how beans were prepared and cooked in the homes.

The most important qualitative attributes of raw beans assessed by consumers include colour (the beans must be intensely black), cleanness (they must be free from dirt, leaves, etc.), smoothness, thin skins, damage (they must not be cracked or broken) and softness (they must be easy to bite or dent with a finger nail).

Guatemalan women seem to prefer the beans to be cooked beyond the point of "doneness" that softens the beans. There may be flavour

enhancement or improvement of broth quality that occurs after texture change.

Although the research groups have soaked beans for up to 24 hours prior to cooking, few Guatemalans pre-soak beans. The beans are usually placed in cold water and simmered for 1-1/2 to 8 hours in iron pots at the edge of the fire. For more information on the focus groups interviews see final report, page 211.

The information gathered by these methods was used to formulate the questionnaire for the survey which will provide a statistical description. The questionnaire design was begun by Brenda Rios and Ruth Diamant in Guatemala last February and has been revised and pre-tested since that time.

The survey will include a sub-sample of respondents who will provide specific information on preferences for raw bean characteristics and the qualities of cooked beans and broth based on a set of standardized samples of these products. Guidelines for the qualities to be examined and defined in the laboratory will be drawn up from the survey results. Ultimately we hope to have a package of tools -- survey methodology, laboratory tests and consumer tests which may be applied to any bean consuming population to determine acceptable varieties and storage practices.

S U R V E Y
(N = 600)

DEPT.	JUTIAPA	CHIMALTENANGO	ESCUINTLA	G.C.
Type of area	Bean producing	Bean producing	Non-producing	Non-producing
Lifestyle	Rural & urban	Rural	Rural	Urban
Cultural group	Ladino	Indian	Ladino & Indian	Ladino & Indian
SES	Low	Low	Low	Low & medium
Altitude (m)	900	1,740	355	1,500

TOPICS

Cleaning, soaking, cooking beans
Criteria for judging doneness
Characteristics of high quality raw beans
Techniques for judging quality
Growing and purchasing beans
Bean storage in the home
Socio-economic characteristics of the family

Discussion

The focus group interviews do not generate numerical data but yield qualitative information which is used in the survey design. They indicate which questions should be asked and the range of possible answers. Using this technique, the survey can be designed so that one answer out of five possible choices can be ticked off and this information can be fed into the computer for analysis. The survey will tell us, for example, what percentage of different language and socioeconomic groups use pressure cookers, or the statistical differences between the "doneness" criteria of these groups.

In non-Spanish speaking groups, local leaders will be trained to do interviews for the survey. The survey will sample 600 people. The women contacted during the focus group interviews were eager to answer questions and to help in an effort to solve the hard-to-cook bean problem. They were also eager to learn about cooking methods that help improve the nutritional quality of the beans. This information will be given at the end of the survey so that the process can be of mutual benefit without interfering with the survey results.

Leesa Chan, University of Manitoba

By calibrating a Mattson cooker using a trained sensory panel, cookability can be measured routinely by the Mattson cooker alone. The Mattson cooker (Mattson, 1946) as used by Jackson and Varriano - Marston (1981) uses 25 plungers and can be adjusted by varying the plunger weight and tip size. Chan is using 85 and 48 gram weights and 2 and 5 mm tip sizes.

Beans are soaked for 18 to 24 hours at about 20°C prior to cooking. They are placed in boiling water and the number of rods to drop are counted every five minutes after the water has returned to the boil. "Doneness" is measured both as the percent cooked according to the sensory panel and as the percentage of the rods dropped.

The trained sensory panel consists of nine to 15 people -- staff and students of the University of Manitoba Foods and Nutrition Department and the Food Science Department. Each panelist tests ten beans five times during cooking to determine the number cooked, and five beans five times for preference. Cookability curves are plotted from the percentage cooked for each cooking time. A panelist evaluation sheet if show on page 207.

Although clearly cooked and clearly uncooked stages were obvious to the panel, it was arbitrarily decided that the stage between these when the beans are soft but still gritty should be considered as cooked.

The first variety to be tested was San Martin, a semi-vine black bean. Even after 200 minutes these beans never reached 92 percent cooked. (see page 208). It is thought that hard shell could cause this problem and, in future, the beans will be graded prior to cooking and any hard-shell beans removed.

Cookability tests are currently being conducted with two vine varieties, Guatemala 993 and 1,430 (see page 209).

Chan will be going to Guatemala in the fall to work with a sensory panel there.

Discussion

It was suggested that the "cookability" as measured by the Mattson cooker might be influenced by the shape or size of the beans as well as by beans with the hard shell defect.

Arnoldo Garcia, INCAP, Guatemala

Guatemala is a small country but one of extremely varied climate and topography. Three main bean growing areas are studied.

Chimaltenango is in the central highlands and has a dry climate and relatively low temperatures (15-18°C).

Jutiapa is in the east of the country bordering El Salvador. It also has a dry climate but higher ambient temperatures (25-30°C).

In these two regions agricultural extension workers will monitor storage practices and collect samples of stored beans. Samples will be taken monthly from ten farmers in each of these areas. New and traditional varieties of both wet and dry season crops will be studied. Because these regions have two major crops per year, the storage period rarely extends six months and hardening will be monitored for six months for each crop.

Peten is in the northern region of Guatemala and has recently been opened up for settlers from the south. It is a relatively new bean growing area and produces only one major crop per year. This area is both hot and humid (30°C, 80-90%RH). Eleven farmers will be involved in the project in this area, monthly bean samples have been collected since March.

Discussion

Although most small-holder farmers produce less than 200 kilograms of beans per year, these farmers are responsible for 80 percent of all beans grown in Guatemala. Most commercial farmers concentrate on corn and other crops.

Although there is a survey planned, there are currently no statistical data on the importance of losses from bean hardening. Preliminary estimates indicate that about 25 percent of beans are affected. In cash

terms, it is estimated that good beans sell for about twice the price of hard-to-cook beans.

As part of the project, a survey will be conducted to evaluate the importance of the hard-to-cook problem in beans.

Storage practices will be monitored during the project and some indigenous technology for preventing hardening may be discovered. Although farmers store beans in several different ways (with or without pods and stems, with oil, ash or peppers) it is thought that these practices are used to protect the beans against insects rather than to prevent hardening.

Working with the agricultural extension service not only allows agronomists to assess the practices of the farmers but has the added advantage that any information generated by the research team can be relayed back to the bean growing regions by those familiar not only with the research effort but with the farmers themselves.

PHYSICAL AND CHEMICAL CHARACTERISTICS OF FOUR VARIETIES OF BLACK BEANS (P. vulgaris)

Variety	Grain weight g	Hardness of soaked grain (g-F)	Protein %	Ash %	Phytates %
San Martin	0.2823	40.8	24.8	4.3	1.4
ICTA Quetzal	0.2066	44.6	23.6	4.3	1.0
ICTA Jutiapan	0.2272	47.6	24.7	4.4	1.4
ICTA Tamazulapa	0.2196	47.1	22.6	3.9	1.0

Incap 85-157

VARIETIES OF BLACK BEANS USED

Improved varieties:	
	ICTA Quetzal
	ICTA Jutiapan
	ICTA Tamazulapa
	ICTA San Martin VB
Bush beans:	
	Compuesto Chimalteco
	IAN 5091
Semivine beans:	
	GUATE 1430
	GUATE 1026-1
Vine beans:	GUATE 933

Incap 85-161

Luis Elias

Possible Uses of Hard-to-cook Beans

The essence of Dr. Elias' presentation is contained in the following flow diagrams.

ALTERNATIVES FOR THE UTILIZATION OF THE HARD-TO-COOK BEANS

DEHULLED BEANS

Hard-to-cook beans*

↓

Blanching
(H_2O, 10-15 min.)

↓

Dehulling
(Disc dehuller, 20 min.)

↓

Cooking**
(Autoclave)

↓

Final product

- - - - - - - - - - -

- Pre-cooked bean flour
- Bean purée
- Mixture of beans with cereals

* The same process will be applied with a recently harvested beans.
** The same bean variety with seed coat will be also cooked.

Incap 84-374

ALTERNATIVES FOR THE UTILISATION OF THE HARD-TO-COOK BEANS

EXTRUSION COOKING

Hard-to-cook beans

↓

Conditioning
(H_2O)

↓

Extrusion
(Appropriate conditions)*

↓

Cooked and dehydrated beans

↓

Grinding

↓

Final product

- - - - - - - - - - -

- Pre-cooked bean flour

* Water content, pre-heating, treatment, cone openings, feeding auger speed and operating temperatures.

Incap 84-372

ALTERNATIVES FOR THE UTILIZATION
OF THE HARD-TO-COOK BEANS

USE OF INORGANIC SALTS

Hard-to-cook beans*

↓

Blanching
(H_2O, 5 min.)

↓

Soaking
Salt solutions*
(25°C-35°C-45°C)

↓

Cooking**
(Autoclave)

↓

Final product

- - - - - - - - - - -

- Fried beans
- Pre-cooked bean flour

---

* NaCl, NO_3PO_4, $NaHCO_3$, Na_2CO_3

Incap 84-373

The food industry in Guatemala has shown interest in these processes which may have potential for the economic use of hard beans. The beans can be purchased at low prices from government storage and there is a ready market for processed bean products. It is hoped that hard beans will be used commercially for extrusion cooking within a year.

V PRESENTATIONS BY INVITED SPEAKERS:

Miguel Mora, University of Costa Rica,
Grain and Seed Research Centre (CIGRAS)

Costa Rica is a bean producing and consuming country and CIGRAS has been studying the problem of hard-to-cook beans for eight years.

Mora reviewed the methods used at CIGRAS for studying the "cookability" of black beans and the trends associated with various storage conditions.

Methodology

Instead of the Mattson cooker or OTMS cell which some researchers use to measure the compressability that indicates whether beans are cooked, CIGRAS uses a standardized "finger test". The beans are squeezed between two fingers and should be completely soft. This test is also used commercially in Costa Rica so the results are applicable to producers and processors. Diamant says that this test is also used in Canada for peas to be sold to a soup company.

Various researchers have used 50 percent, 90 percent or 100 percent of beans cooked to measure cooking time (the Manitoba team uses 92 percent). The relationship between these standards is shown on page 254.

Although the source of heat (gas or electricity) did not affect cooking time, the hardness of the cooking water was shown to be important. Cooking time increased with the salt content of the water used (see pages 246, 255).

Storage

A marked increase in hardness was found in beans stored at more than 25°C. After 18 months, beans stored at 35°C took 375 minutes to cook compared to 60 minutes before storage began. When stored at 20°C, cooking time increased to only 112 minutes over 18 months (see page 251).

Although the moisture content of the stored beans was also found to affect cooking time, a difference of less than 50 percent was seen between beans stored for 18 months at 13 percent and 16 percent moisture (see page 252). Lower moisture contents were not studied.

Several cultivars of black and red beans were studied. There were no significant differences in cooking time as influenced by storage (see page 249).

Neither sealed storage or pre-storage heat treatment (125°C for up to 15 minutes) were found to affect hardening significantly (see page 258).

Mora reports that beans stored at various moisture contents and temperatures hardened for the first year of storage. After that all samples showed a decreased cooking time, a reversal of the hardening trend. In samples stored at 20°C or more and at 15.5 percent moisture, the beans began to harden again after 16 months. Although this phenomenon has not been reported by other researchers, Mora says that these tests are reliable and the results significant (see page 257). During discussion it was suggested that "hard shell" which has been found to be reversible could be partly responsible for these observations.

Maria Regina Sartori, ITAL, Brazil

Sartori has been working in Brazil and at Kansas State University, USA, on semi-industrial and lab scale bean storage tests. She reviewed the major studies carried out in Brazil on bean hardening and the methodologies used (see pages 259-291).

Aeration of beans stored in metal bins was found to be economical when ambient air cooler than 18°C and with relative humidity less than 85 percent, was used. Aeration with chilled air significantly improved flavour, texture and appearance over those aerated with ambient air. After nine months storage, the chilled beans cooked 50 percent faster than controls.

Storage of pinto beans under a continuous flow of nitrogen did not significantly reduce hardening or affect texture but it did decrease darkening of beans with storage time (see page 271).

Studies on various cooking methods show that the addition of 0.5 percent hexametaphosphate to the cooking water decreased cooking time of beans.

Statistical methods of flavour and texture evaluation are described. Sartori pointed out one problem with the "hedonic" scale used. The sensory panel in Kansas preferred the "dry bean" flavour that develops in old beans to the "raw vegetable" flavour of fresh beans. This is the opposite of preferences in Brazil.

VI METHODOLOGICAL ISSUES

Beverly Watts, Chair

Sample Preparation and Standardization

The research groups within the network need to know exact methodologies used by each team.

Cooking time

The Guelph/Chile project cooks beans for two hours before testing for compressibility. Because the Manitoba/Guatemala project is examining cooking time, they do not use a set time but cook beans until they are "done".

Cooking time can be measured from time zero or from the time the cooking water regains boiling. The Manitoba team uses the latter method.

Storage conditions

Relative humidity, temperature and packaging during storage should be reported.

Units for reporting

Sample size still needs to be standardized.

Hardness can be measured in newtons required to compress or in relative hardness of stored to unstored beans. The groups from Guelph and Chile prefer the relative hardness method of reporting but this data may also be required to be reported in newtons.

Cooking Quality Factors

1) hardness -- of raw and soaked beans measured as Kramer shear stress using wedge
-- of cooked beans using OTMS 10^2 cm cell

2) DURINCAP puncture test

3) water absorption -- the Guelph team suggests their method

4) initial moisture of beans

5) size of beans

6) colour of beans

7) colour of broth

8) viscosity of broth

9) proximate analysis

10) type of water used for cooking beans.

Equipment

1) Wedge

The Manitoba team plans to acquire one but does not presently have a wedge for measuring shear stress of raw and soaked beans. They need exact specifications of the wedge used by the Guelph team in order to get one manufactured.

2) OTMS cell

The 10^2cm cell is used to measure compressibility of cooked beans. At present the Guelph and Chilean teams have these and the Manitoba team has one on order. The Manitoba team plans to buy a computer link that is correlated with the system used by Agriculture Canada. The possibility of dropping the computer link was discussed. Purchase is presently being delayed because there is a "blip" in the system; it is not known whether the fault is in the software or hardware component. The Guelph team does not use a computer link.

An alternative to the OTMS cell, a less expensive ($10,000 compared to $25,000) Canadian model was discussed. Concerns were expressed about the service for and adaptability of the Canadian cell.

3) Mattson cooker

The Manitoba team uses the cooker (see page 193 for illustration) to measure cooking time required to soften beans.

Discussion of the relationship between the data generated by the Mattson cooker and the OTMS cell.

The Mattson cooker is adjusted so that it measures "doneness" as calibrated by the sensory panel. The relationship between the OTMS cell data and the results from the sensory panel are unknown.

The trained sensory panel measures hardness, grittiness, "hulliness", fracturability and flavour characteristics. The panel's results are objective and can be reproduced in Guatemala and elsewhere. The sensory panel does not indicate subjective preferences.

The consumer preference survey will show which beans people like or don't like. These results will be available by the end of the summer but they will not, in themselves, tell how much hardness affects preference. A value for acceptable hardness will only be obtained by correlating that data with the sensory panel's description of the characteristics of beans. This will show the relative importance of hardness to preference and therefore how much hardness is acceptable to consumers in Guatemala. Only then, at the end of this phase of the project, will the Mattson cooker be used to tell "how hard is too hard" in Guatemala, so that the OTMS cell can be correlated to consumer acceptability.

Sensory Panel

In the meantime, sensory panel data on the relative hardness that is perceptible to the consumer will soon be available. These data will not, however, show how much hardness is acceptable to the Guatemalan consumer. At the end of the project, the Manitoba team should be able to determine the relative importance of grittiness, seed coat, flavour and other factors as well as hardness as expressed by multiple regression. These data will be useful for the Guelph/Chile teams to assess the treatments used (such as heat treatment) to prevent hardening as well as how much hardness is acceptable.

VII PLANNING FOR INTERPROJECT INTERACTION AND INTEGRATED REPORTING

Jose Miguel Aguilera, Chair

Although there have been interproject visits, annual meetings and reports, there is a lack of inter-network communication and collaboration. The annual reports and trip reports required by IDRC along with theses and papers submitted to journals are, in themselves, a burden to research groups. In addition, researchers are reluctant to report data and experimental results prematurely. Each group within the network must, however be kept informed of the latest approaches taken and data generated by researchers.

Network communication could be improved by making trip reports serve the needs of the network rather than merely fulfulling the administrative requirements of IDRC. Similarly, the annual report required by IDRC should be more collaborative, including interpretive comparisons that reflect the integrated network as well as the efforts of individual research teams.

At present, each team is working on an aspect of the problem presented by hard-to-cook beans but no one is specifically responsible for the entire collaborative effort. Co-ordination of the network is, in itself a major task. Stanley suggested that IDRC should be responsible; Edwardson replied that IDRC Program Officers are not staffed to take on the work load involved.

As the network research components become closer to reaching their individual goals, the necessity for collaboration will increase. The possibility of hiring someone (or part of a man-year) specifically to co-ordinate network activities was discussed. Since funds have not been allocated for such a position within this phase of the project, it is suggested that a request for a part-time network co-ordinator should be discussed at the 1986 annual meeting and possibly included in the next phase of the project. As the project results begin to merge toward the common goal, network co-ordination will become increasingly complex and essential.

In the meantime, network co-operation will be improved by quarterly progress reports produced by each group in September, December and March and June. Edwardson volunteers to act as a "smart postbox" distributing research results, progress reports and travel reports to network groups.

VIII CO-ORDINATION OF NETWORK ACTIVITIES/NEXT WORKSHOP

Luis Elias, Chair

Interaction depends on each group getting needs met by other network groups.

Needs to be fulfilled by the network include;

1) beans, both untreated and pre-treated are supplied by Chilean team to the Guelph and Manitoba teams.

2) acceptable levels of hardness determined by the Manitoba/Guatemala team will provide threshold levels to the Guelph/Chile team as well as the effects of pre-storage treatments on other parameters.

3) Guelph will do some microscopy work for the Manitoban team if required.

Nomenclature

The eventual standardization of abbreviations may be necessary but in the meantime all samples should be labelled in full with the following:

1) country
2) location within the country where they are grown
3) variety (pedigree)
4) date of harvest
5) history from date of harvest to controlled experimental treatment
6) treatment prior to storage
7) initial moisture content
8) packaging
9) storage conditions (length of time stored, percent relative humidity, temperature in °C throughout storage)
10) fumigation prior to export (phostoxin)

Sample Transport

Chilean samples are sent to Guelph after pre-storage treatment. They are stored under controlled conditions at Guelph University. This year the Manitoba team will also be working with Chilean beans. Since Manitoba has no access to controlled storage, the beans will be shipped to Guelph where they will be stored until the Manitoba team requires them. Because the Guelph team has limited storage it will store only about two kilograms under each storage condition.

The Guatemalan team sends samples to the Manitoba team after set storage intervals.

There have been several near disasters with samples being lost or delayed through the airlines and mail system. Whenever possible, samples should be sent with visitors from other teams.

1986 Annual Meeting

Extra-network participation.

The advantages and disadvantages of inviting outside participants were discussed.

Advantages -- additional expertise brought to the problem
-- different perspectives on methodology and approach
-- opportunity for IDRC and other network members to assess the possibility of extending the network to include other institutions
-- opportunity to assess possible interactions between network and non-network institutions

Disadvantages

-- non-network members could inhibit frank discussion of administrative and other housekeeping matters. The possibility of these issues being discussed in small, network-only groups of project managers during the first day of the meeting was raised.

Location

Guatemala is suggested as the site of the next annual meeting. The advantages cited include: 1) to allow greater attendance by members of the Guatemalan team and 2) to allow members of the Canadian teams to better appreciate the problem of hard-to-cook beans in the context of small-holder production, storage conditions, the marketing system and consumption in Guatemala -- "to let them taste black beans from a clay pot beside the fire."

Date

It was agreed that the next meeting should be longer than two days to allow more informal interaction between network teams and individuals. A duration of four to five days was suggested to allow part of each day to be devoted to visits to producers, consumers, markets, bulk storage facilities and industrial processors. Closed meetings for project leaders could be accommodated on first and last days of meeting.

The meeting is tentatively scheduled for some time during the last three weeks of May. As this is the time when the land is being cultivated and beans are being planted, there will be few beans remaining in on-farm storage.

IX EXTRA-NETWORK ISSUES

Dave Stanley, Chair

1) Nutrition - Non-members of the network have expressed interest in working on the nutritional aspects of the hard-to-cook bean phenomenon. The network members think that this component will be adequately covered by information available in the literature supplemented by research planned by the INCAP group.

2) Agronomic - INCAP presently has two agronomists engaged in the project to monitor bean cultivation, harvest and post-harvest practices.

3) Economic - There is little information available on the economic losses resulting from bean hardening. The Guatemalan government has not estimated either the energy or economic losses involved. Although CIAT is doing agricultural research in Guatemala, their work reportedly concentrates on yields, marketing and physical losses rather than on bean quality.

The INCAP project plans to include questions about losses due to bean hardening in the questionnaire to be used for the survey of producers. The possibility of consulting economists from ISER, CIAT or IDRC about the wording and interpretation of the survey was suggested.

The survey should give farmers perceptions of losses while actual losses will be monitored by the agronomists on the project.

X UTILIZATION OF RESULTS

Bill Edwardson, Chair

Beneficiaries

1) farmers - The Chilean team will be developing a prototype design for pre-storage treatment in the final year of the project to be tested in on-farm conditions. The site of prototype introduction will be made by educated choice rather than extensive study. There is no plan for a farming systems survey. The economic evaluation of pre-treatment will be left to the producers. These aspects will need review later in the project.

2) national institutions and co-operatives -- If effective pre-treatments or controlled storage conditions are not applicable to small-holder farmers, they may benefit farmers through improving the quality of bulk storage. In both Guatemala and Chile, the majority of beans stored for prolonged periods are held in bulk storage.

3) other bean-consuming countries -- The Guatemalan and Manitoban teams plan to produce a manual from the results of their consumer preference and sensory analysis research which will be applicable in other bean-consuming countries.

4) plant breeders -- CIAT has already expressed interest in methods for screening varieties for storage characteristics. The Guelph team suggests that the wedge test used on raw beans correlates well ($R^2 = 0.98$) with compressibility of cooked beans. This method is quick and can be used on a large number of samples.

   The Chilean team may be able to assess the accuracy of accelerated storage condition results.

XI RESEARCH DIRECTION AND WRAP-UP

It has been established by other researchers and corroborated by this network that:

1) The conditions that cause bean hardening are prolonged storage, high temperatures, high relative humidity

2) Hardening can be reduced by controlling the storage environment.

The questions that remain unanswered include:

1) How can hardening be prevented under adverse storage conditions? Has roasting a role?

2) Why hardening sometimes seems to stop or even occasionally to be reversed?

3) What are all the mechanisms that contribute to hardening?

4) Are the mechanisms (and their relative importance) the same under different storage conditions? Storage conditions which accelerate hardening are used to evaluate new varieties. This may not be duplicating the same hardening process that occurs in field conditions.

5) How hard is too hard? What are the acceptable levels of hardness in stored beans and which other factors affect consumer preference?

6) Is there an economical way of controlling storage conditions to reduce hardening?

WRAP-UP

Marion Vaisey-Genser

Collaborative research is a new experience for those who have come to this network accustomed to individual research efforts and achievements. We have all earned our spurs in different directions and now take up the challenge and opportunity offered by the communication tools of today to work co-operatively toward a common goal.

We have learned a lot at this workshop and in the coming year we will be more conscious of the larger goals. As we write our reports we will pay attention to the entire network of four groups instead of merely our own groups and pairs.

IDRC has delivered the message that the project members must be responsible for our own network but IDRC is part of the network too. We are all in it together, working toward shared goals. We are all involved in this kind of research, research transfer and development of human resources because we chose to participate.

It has been helpful to look ahead to the second phase of the project, to plan toward future integration and application of our research and to remember not to be frustrated by not reaching all of our goals within the first phase.

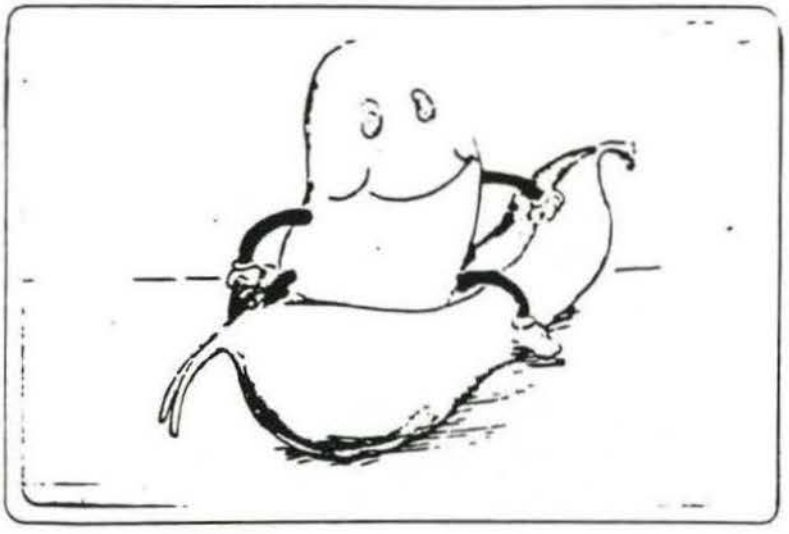
Because it is the first time the two teams have met to share information, we will benefit from the chance we have had to compare methodologies and learn what production is expected from the other network members. By the next network meeting we should be able to show the spin-offs from the one-on-one contacts that are developing. We have all aired our opinions and each of us will be able to take advantage in different ways.

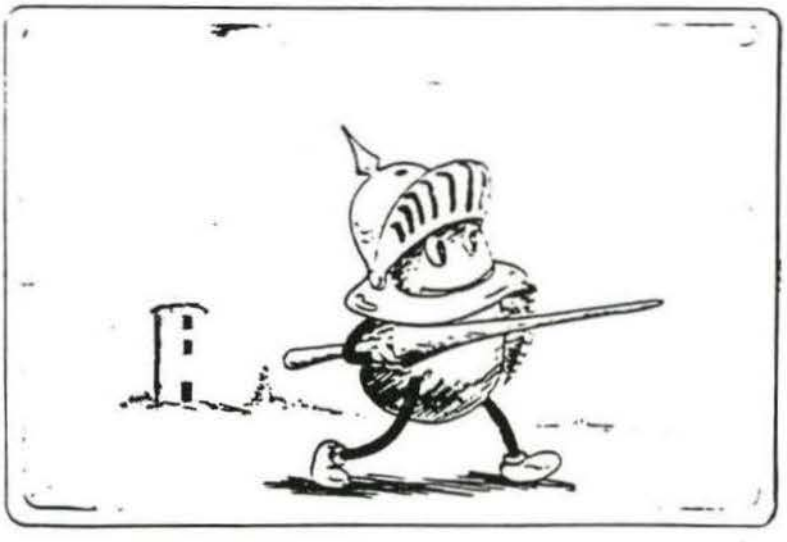
Our challenge will be to continue the interaction -- to spend more of our budget on phone bills. As we strengthen communication within and across institutions and as our research develops, we should derive even more from our next meeting. Let us hope that we can take up the challenge of the network and benefit from our differences.

PAGE

APPENDIX I

Additional information from Guelph/Chile teams





PROCESSING ASPECTS OF BEAN STORAGE

By J.M. Aguilera and Wanda Villablanca

Objectives:

1) To develop a generalized kinetic model to bean hardening phenomenon. This means finding a relationship between hardening rates and environmental conditions such as temperature of storage, moisture content of beans and time

2) To evaluate particle-to-particle roasting as a processing alternative to retard hardening, dry the beans to lower moisture contents and use it as a pasteurization device.

Findings:

- Untreated beans stored at three temperatures (8.5, 25 and 45°C) and moisture contents ranging from 8.5 to 14.0 hardened under all sets of conditions (fig. 1)

- Hardening proceeded as a zero order reaction at low temperature (8.5 and 25°C) and as a first order reaction at 40°C.

- Bean hardening reached a plateau and was stopped at 8.5 and 25°C probably due to changes in the atmosphere inside the sealed polyethylene packages prompted by respiration

- Hardening occurred much faster at 40°C than at any other temperature. The effect of moisture at high temperatures is reduced (fig. 1)

- Drybeans roasted for two minutes to average temperatures ranging from 50 to 110°C hardened in all cases (fig. 2)

- Initially (time 0, fig. 2) lower force values were obtained for samples roasted between 80 - 90°C. Samples like the control (20°C) and those roasted up to T 80°C seemed to harden to a certain level and after about 135-180 days the process was hastened. Samples roasted 100°C kept on hardening after 270 days of storage even though they could not germinate (fig. 2)

- Beans roasted at 80°C and stored under similar conditions as the controls were also examined for kinetic effects (fig. 3). As was the case with control beans (fig. 1) low temperatures induced zero order kinetics while at 40°C a 0.5 degree order kinetic fitted the data best

- Roasted beans stored at low moisture and high temperature (40°C) hardened at a lower rate than untreated beans. Roasting apparently does have a signficant effect in retarding hardening only when moisture is kept low during storage.

Also, roasting had a drying effect (fig. 4) as well as a checking effect on infestation, that is being studied.

Finally, roasting using hot sand as medium was very effective in producing uniform heating in beans (fig. 5)

Figure 1

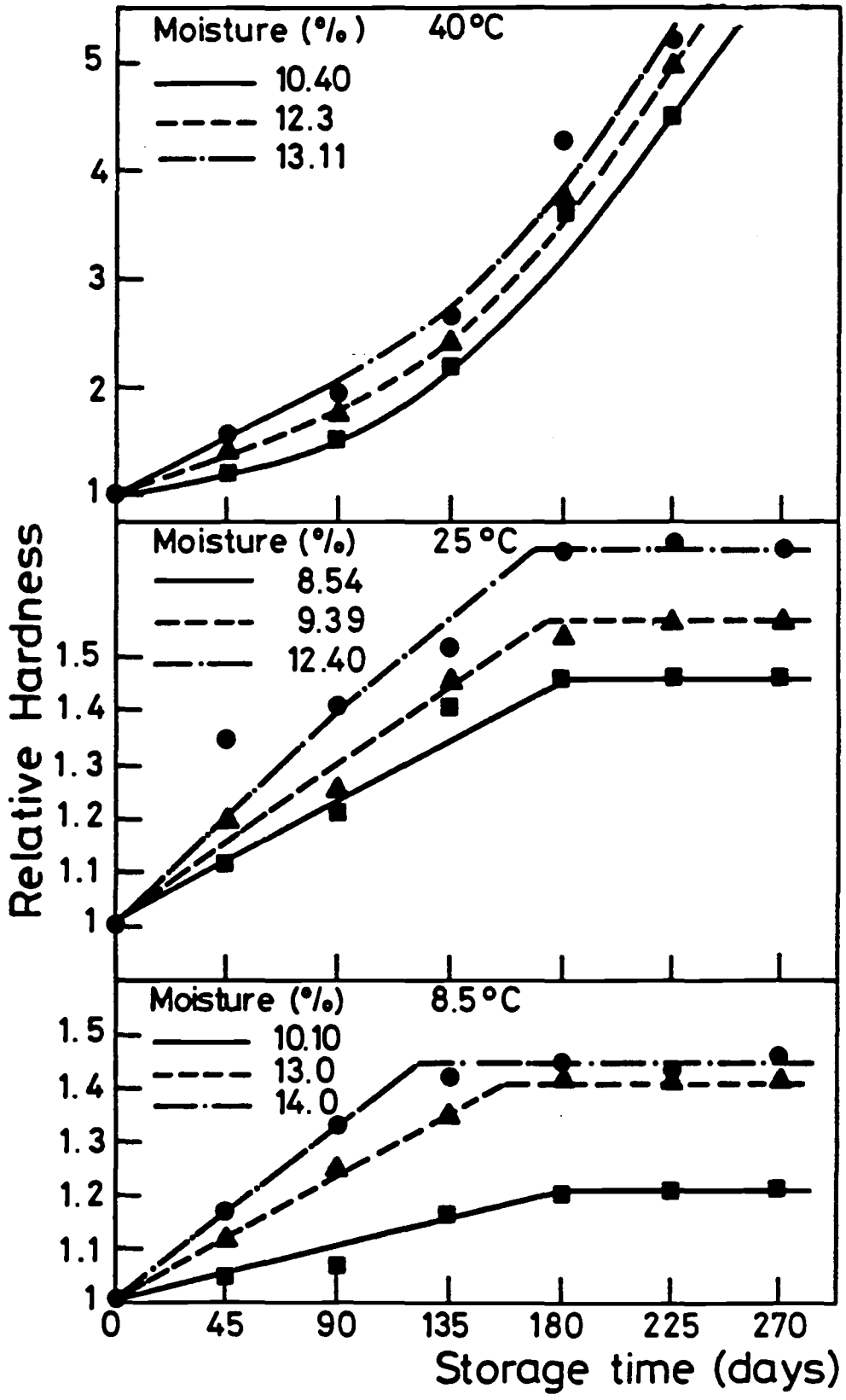

Moisture (%) 40°C
10.40
12.3
13.11
Moisture (%) 25°C
8.54
9.39
12.40
Moisture (%) 8.5°C
10.10
13.0
14.0
Relative Hardness
Storage time (days)
0
45
90
135
180
225
270

Figure 2

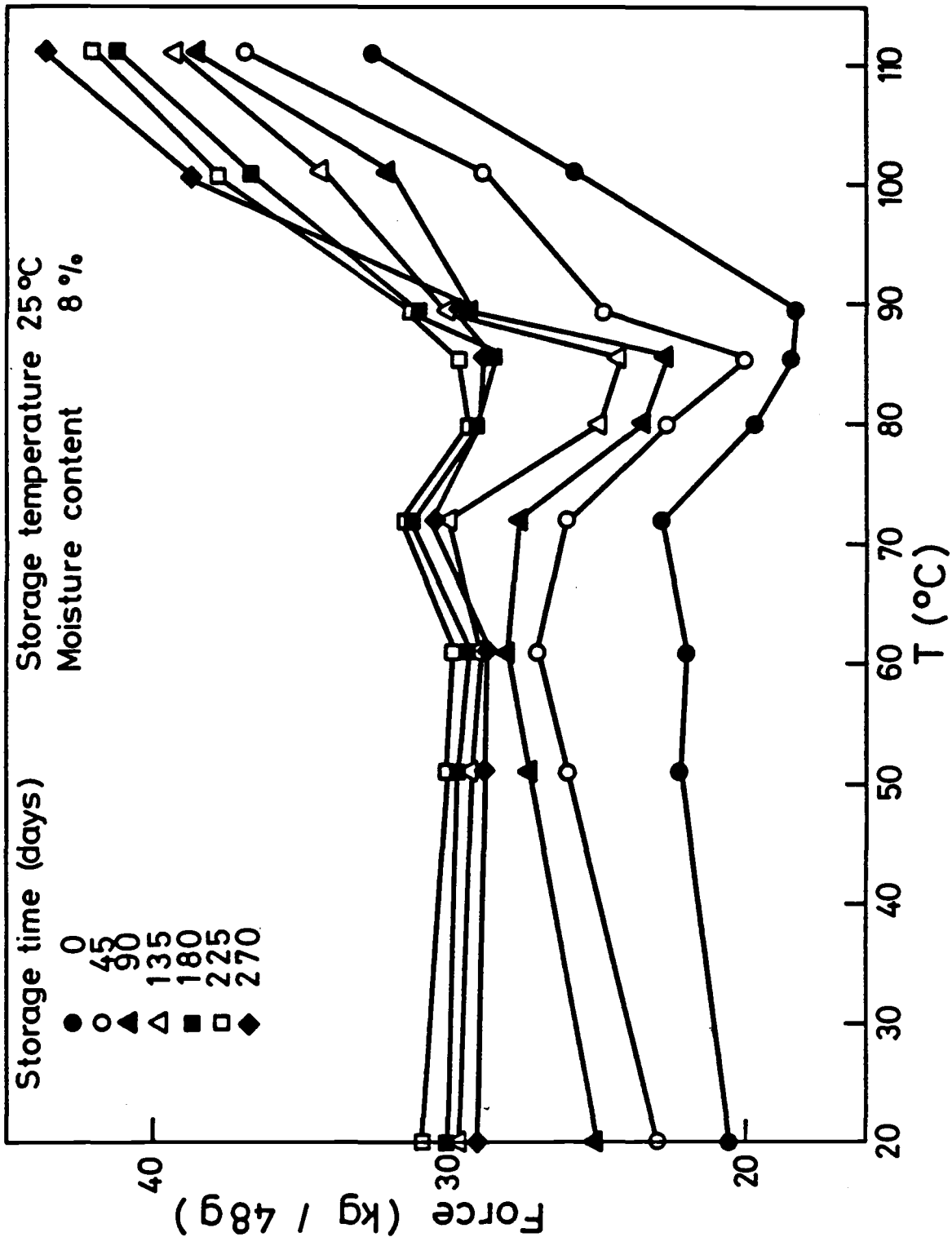

Storage temperature 25°C
Moisture content 8 %
Storage time (days)
0
45
90
135
180
225
270
Force (kg / 48g)
40
30
20
20
30
40
50
60
70
80
90
100
110
T (°C)

Figure 3

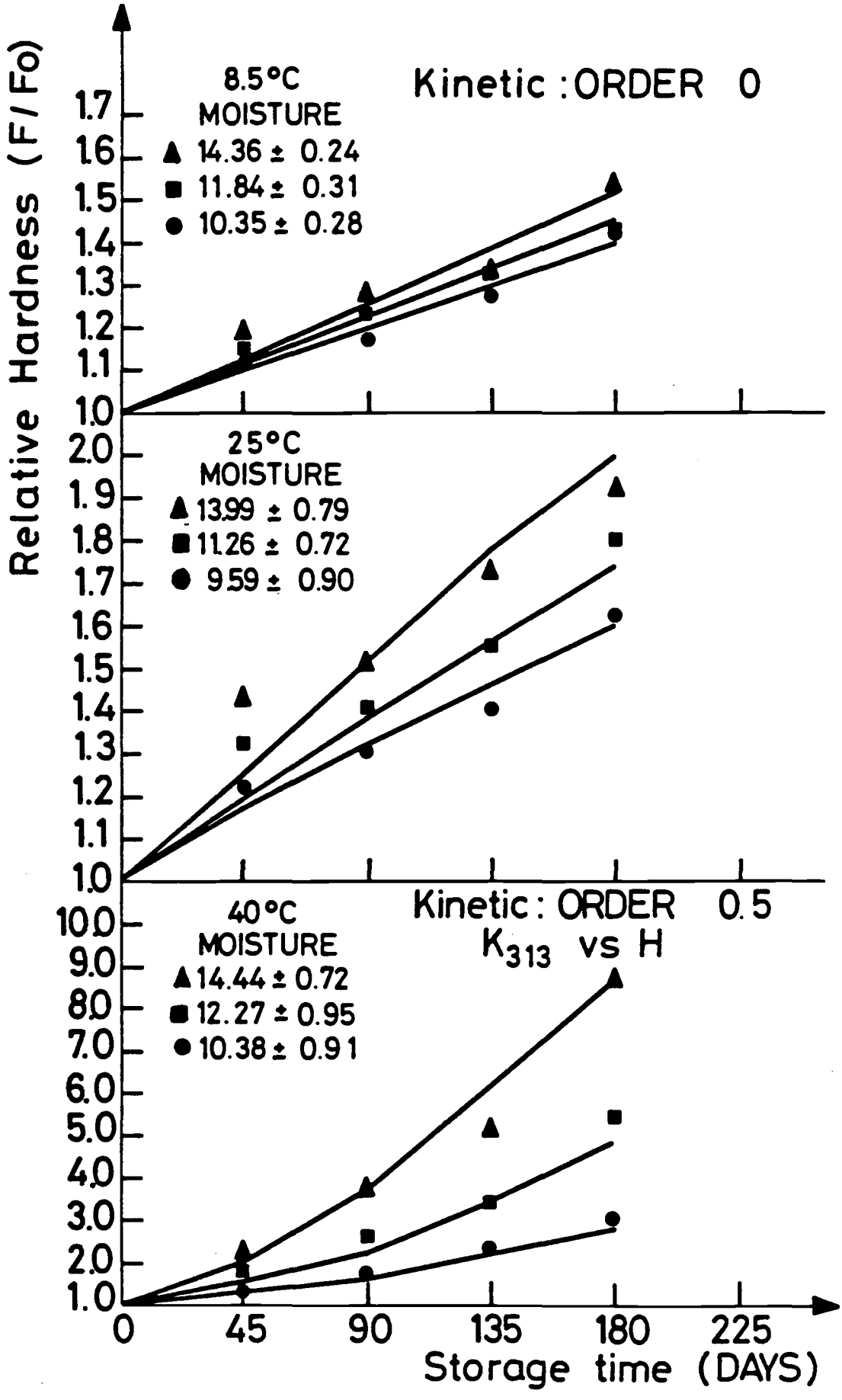
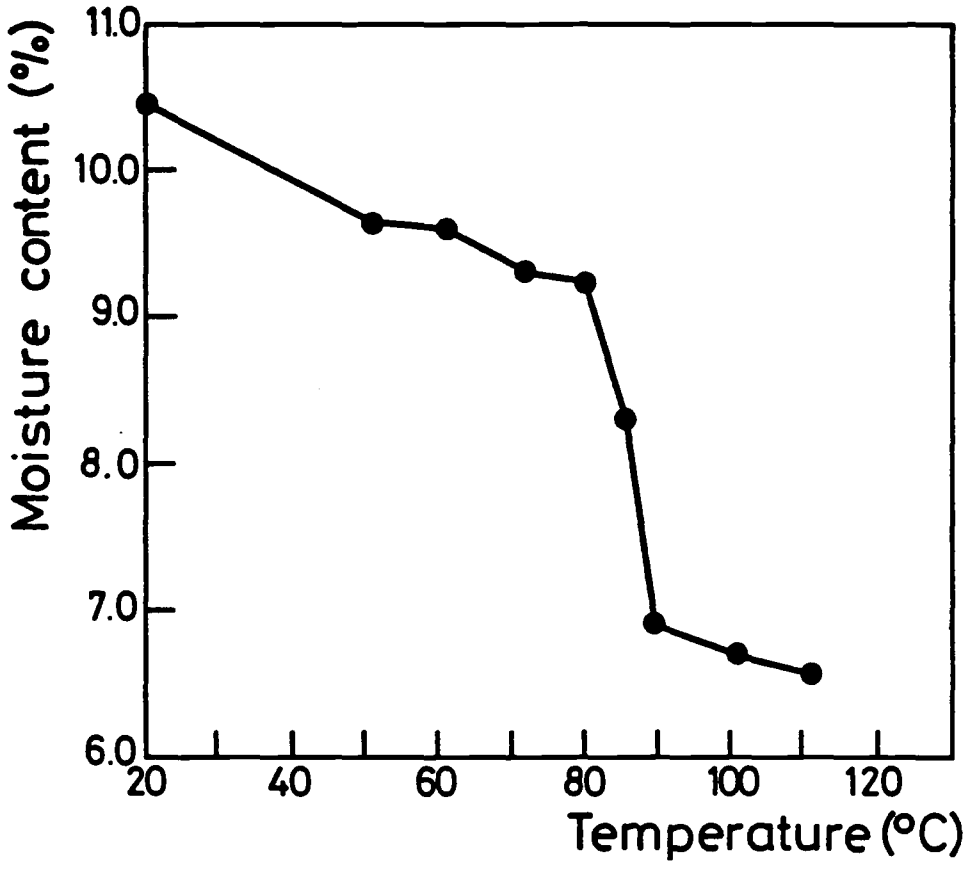

Relative Hardness (F/Fo)
8.5°C
MOISTURE
▲ 14.36 ± 0.24
■ 11.84 ± 0.31
● 10.35 ± 0.28
Kinetic : ORDER 0
25°C
MOISTURE
▲ 13.99 ± 0.79
■ 11.26 ± 0.72
● 9.59 ± 0.90
40°C
MOISTURE
▲ 14.44 ± 0.72
■ 12.27 ± 0.95
● 10.38 ± 0.91
Kinetic : ORDER 0.5
K_{313} vs H
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
45
90
135
180
225
Storage time (DAYS)

Figure 4


Moisture content (%)
11.0
10.0
9.0
8.0
7.0
6.0
20
40
60
80
100
120
Temperature (°C)

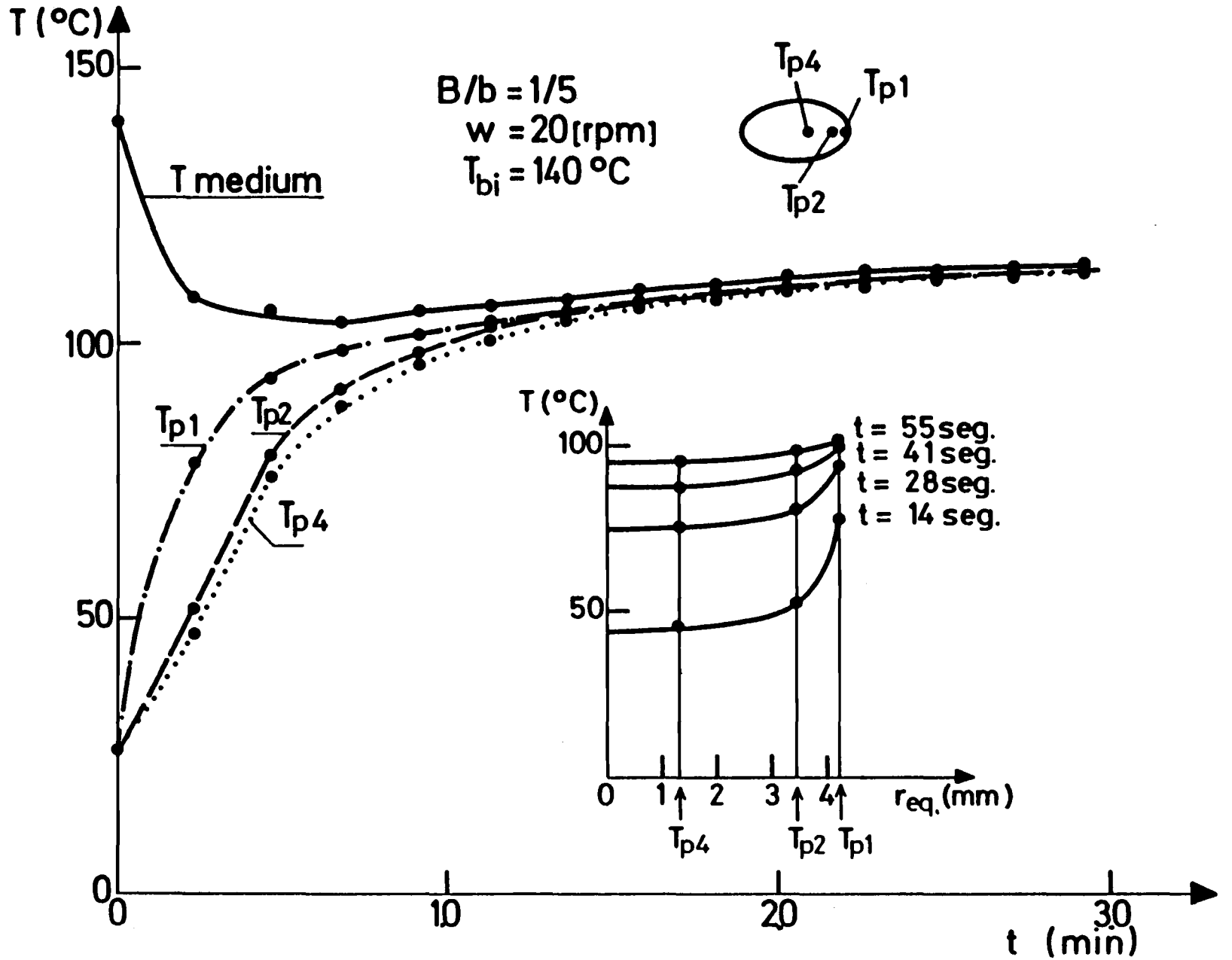

T (°C)
150
100
50
0
0
10
20
30
t (min)
B/b = 1/5
w = 20 [rpm]
T_{bi} = 140 °C
T medium
T_{p1}
T_{p2}
T_{p4}
T_{p4}
T_{p1}
T_{p2}
T (°C)
100
50
t = 55 seg.
t = 41 seg.
t = 28 seg.
t = 14 seg.
0
1
2
3
4
$r_{eq.}$ (mm)
T_{p4}
T_{p2}
T_{p1}

Figure 5

Michael Hincks, University of Guelph

Legume seeds constitute an important protein source in the diets of populations for which they are a traditional food (Molina et al., 1976); beans of the Phaseolus vulgaris species may provide up to 50 % of their dietary protein (Varriano-Marston and de Omana, 1979). Maximum use of this food source is curtailed by post-harvest losses related to storage, in particular the development of the hard-to-cook defect which is potentiated by high temperature and high humidity storage conditions. Beans suffering from this defect require extended cooking time to reach acceptable tenderness levels. This, in turn, leads to increased energy expenditures, minimal consumer acceptance due to quality deterioration, and economic losses. A comprehensive understanding of the fundamental cause(s) of this defect is required in order to establish adequate processing and storage methods to prevent its development. The following proposal includes a brief review of the literature concerning possible mechanisms responsible for the hard-to-cook defect, a synopsis of research conducted to date and an outline of future research.

The hard-to-cook phenomenon in beans is often confused with another textural defect known as hardshell, thus it becomes necessary to discriminate between the two. Hardshell is defined as the lack of water imbibition by a seed. This has been attributed to the structural characteristics of the testa and its chemical composition (Muller, 1967; Saio, 1976; Rolston, 1978; Sefa-Dedeh and Stanley, 1979a,b). The hard-to-cook defect is characterized by the restricted softening of the bean cotyledon upon cooking. This is thought to be the result of changes within the middle lamella or cell wall which prohibit cell separation.

The hard-to-cook defect is brought about by adverse storage conditions of high temperature and high humidity (Molina et al., 1976; Sefa-Dedeh and Stanley, 1979c; Jackson and Varriano-Marston, 1981; Jones and Boulter, 1983). Several mechanisms have been proposed to account for its development. These can be divided into two categories, viz. enzymatic and chemical.

Storage at elevated temperatures and humidities is believed to initiate a false germination of the legume, resulting in restricted metabolism and increased enzyme activity due to an increased water activity (a_w). The proposed enzymatic pathways have been summarized in Figure 1 and are discussed below.

The role of phytase as a contributor to increased cooking time has received much attention (Mattson, 1946; Mattson, 1950, Kon, 1979; Moscoso et al., 1984). This enzyme hydrolyzes phytate to inositol and inorganic orthophosphate. Phytate is a powerful natural chelator of divalent cations and it is thought that

destruction of this chelating potential decreases the exchange of Ca^{++} and Mg^{++} for Na^{+} and K^{+} in the middle lamella during the soaking and cooking processes. This inhibits solvation of the middle lamella, thus preventing the separation of cotyledonary cells during cooking. An increase in the formation of insoluble calcium and magnesium pectates may be facilitated by pectin methylesterase, as its action of de-esterification to increase the free carboxyl groups of pectin would allow further interaction with divalent cations.

Another enzymatic pathway which may be of importance is that of lignification. Lignin is an extremely insoluble compound that may further increase cell bonding in the middle lamella/cell wall complex. There are several points along this pathway where the lignification process could be enhanced. Autolytic degradation of storage proteins in the seed tissue provides increased amino acid pools. The aromatic amino acids, tyrosine and phenylalanine, serve as precursors for lignin monomers (Goodwin and Mercer, 1972). Increased protease activity has been observed in beans stored under adverse storage conditions (Ching and Schoolcraft, 1968; Stanley and Aguilera, 1985).

Lignin is a product of the oxidation and polymerization of polyphenols. This oxidation may occur either enzymatically by the action of polyphenol oxidase or non-enzymatically (Blouin et al., 1982). Two important points arise at this juncture;

1. Lignin precursors can interact with proteins, and the product of this peroxidase catalyzed reaction has been suggested as the initial step of lignification (Whitmore, 1978).

2. Non-enzymatic oxidation of polyphenols means that lignification may occur even though enzymes have been inactivated due to storage conditions or pre-treatment such as heat. This is one chemical mechanism which possibly participates in the development of hard beans. It should be noted that black beans have the highest quantity of polyphenols, mainly concentrated in the seed coat (up to 1.29% expressed as tannic acid) (Bressani and Elias, 1980).

Another enzyme system has been implicated for its possible role in the hard-to-cook defect. Priestly and Leopold (1979) suggested that the action of phospholipid hydrolyzing enzymes lead to net membrane degradation, resulting in decreased turgor and minimal cell separation. This may be supported by evidence obtained from transmission electron microscopy showing the detachment of the plasmalemma from the cell wall and the disintegration of organelles in hard-to-cook beans (Hallam et al., 1972, Varriano-Marston and Jackson, 1981). This breakdown would also enhance global enzyme/substrate interaction.

This brief review of postulated mechanisms supplies a basis upon which further research can be planned. The objectives of this study are twofold:

1. To determine the possible cause(s) of the defect and elucidate the mechanism(s) responsible.
2. To investigate ways by which the reaction can be controlled.

Fig. 1 - Proposed mechanism for "hard-to-cook defect"

Fig. 2 - General research plan for year 1

Fig. 3 - Absorption characteristics of 4 treatments
It was imperative to establish whether textural changes were attributable to the hard-to-cook or hardshell defect. As shown, water absorption for all treatments was very similar indicating that hardshell was not in evidence.

Fig. 4 - Texture of Cooked Beans

a) The hard-to-cook defect was initiated in those beans stored under high humidity and high temperature conditions, commencing by the 4th month of storage. Under the conditions specified in Fig. 2, heat treatment did not appear to reduce hardness.

b) Texture of Raw Beans. Raw texture showed a rapid increase for those beans stored under HH(high/high) conditions in the 1st month and remained relatively constant over storage time at this elevated force. It is of interest to note that these beans were also those having the highest moisture levels (Fig. 5). These results may prove useful in a practical sense as raw texture might be applied as a predictor of the subsequent hardening defect.

Fig. 5 - Moisture content of beans over storage

Fig. 6 - phytate levels
A general decrease in phytate levels seen over storage time with the rate of phytate degradation being most rapid in RDHH and HTHH beans.

Fig. 7 - Phytase activity

Phytase activity trends were as follows: RDHH beans showed an increase in activity while HTHH showed little change yet remained at elevated levels over time.

Low temperature and humidity storage caused a depression of phytase activity initially, however after 4 months activity began to increase. This lag effect may account for higher final phytate levels as seen in Fig. 6.

Conclusion: Although it would appear that trends indicate lower phytate levels and elevated phytase activities are associated with the hard-to-cook defect. This mechanism cannot be ascribed the sole or perhaps even the dominant role in the hard-to-cook phenomenon.

Fig. 8 - Scanning electron micrograph of bean microstructure; composite plate of increasing magnification left to right, top to bottom.

Fig. 9 - SEM of A) RDLL - cooked
B) RDHH - cooked

Again, decreased cell separation is evident in the beans which have been stored under HH conditions. This close, compact cell arrangement which has a decreased tendency to separate is most likely associated with the sensory perception of "hardness"

Fig. 10 - Middle lamella cell wall isolate (SEM micrograph)

Figure 1

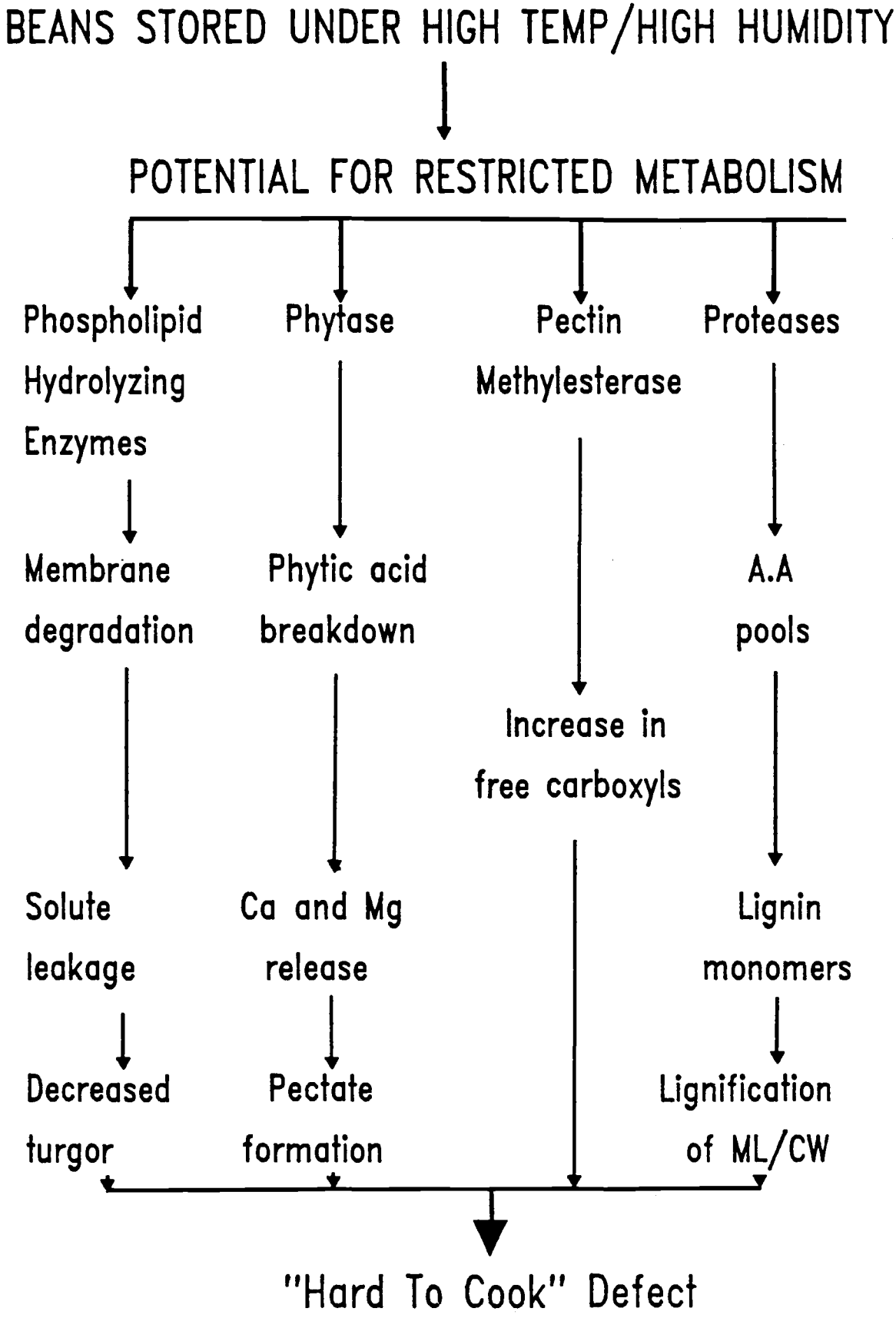
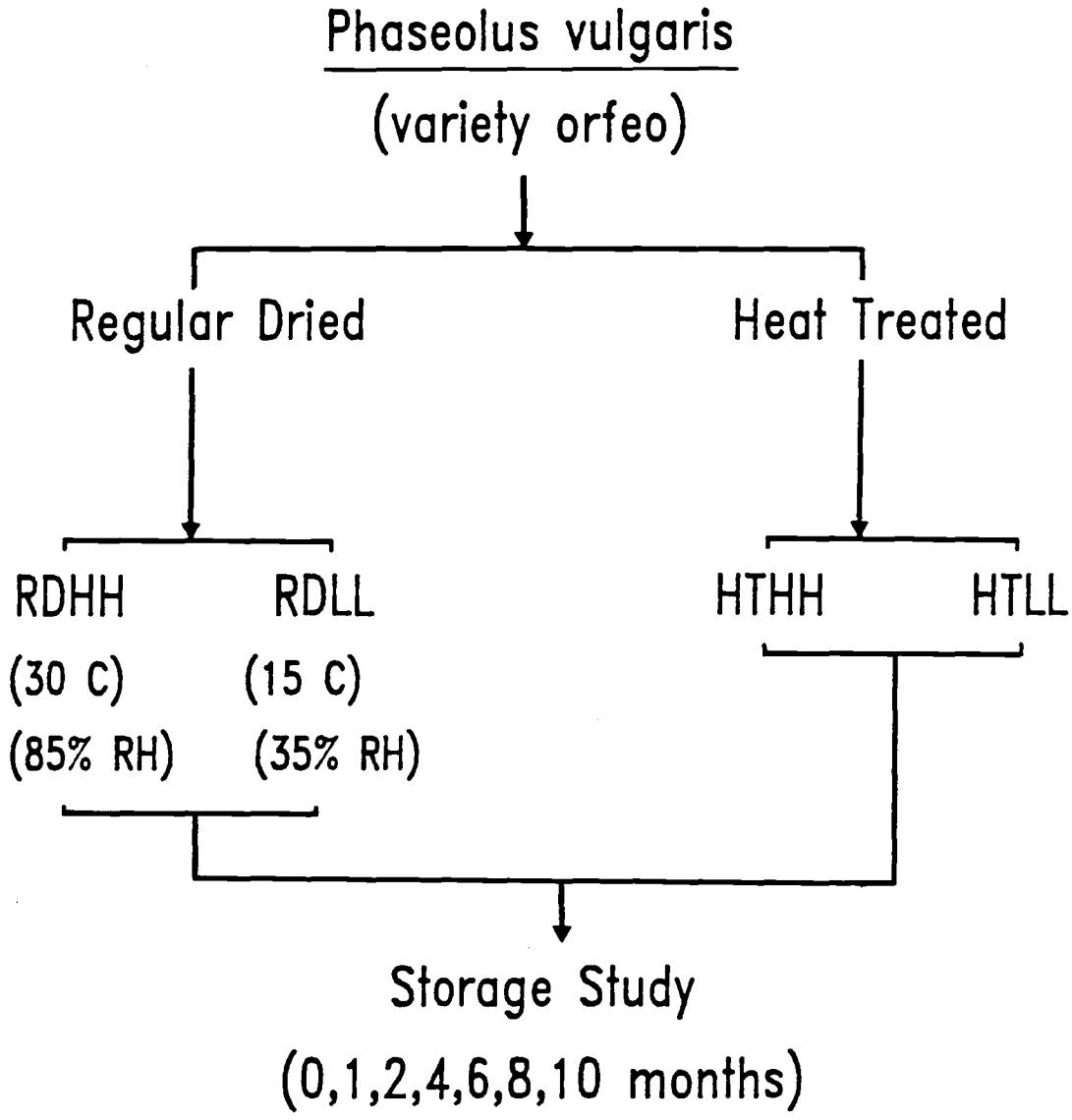

BEANS STORED UNDER HIGH TEMP/HIGH HUMIDITY
POTENTIAL FOR RESTRICTED METABOLISM
Phospholipid Hydrolyzing Enzymes
Phytase
Pectin Methylesterase
Proteases
Membrane degradation
Phytic acid breakdown
A.A pools
Increase in free carboxyls
Solute leakage
Ca and Mg release
Lignin monomers
Decreased turgor
Pectate formation
Lignification of ML/CW
"Hard To Cook" Defect

Figure 2



1. Water absorption
2. Texture of raw, soaked and cooked beans
3. Moisture
4. Phytase activity
5. Phytate

Figure 3

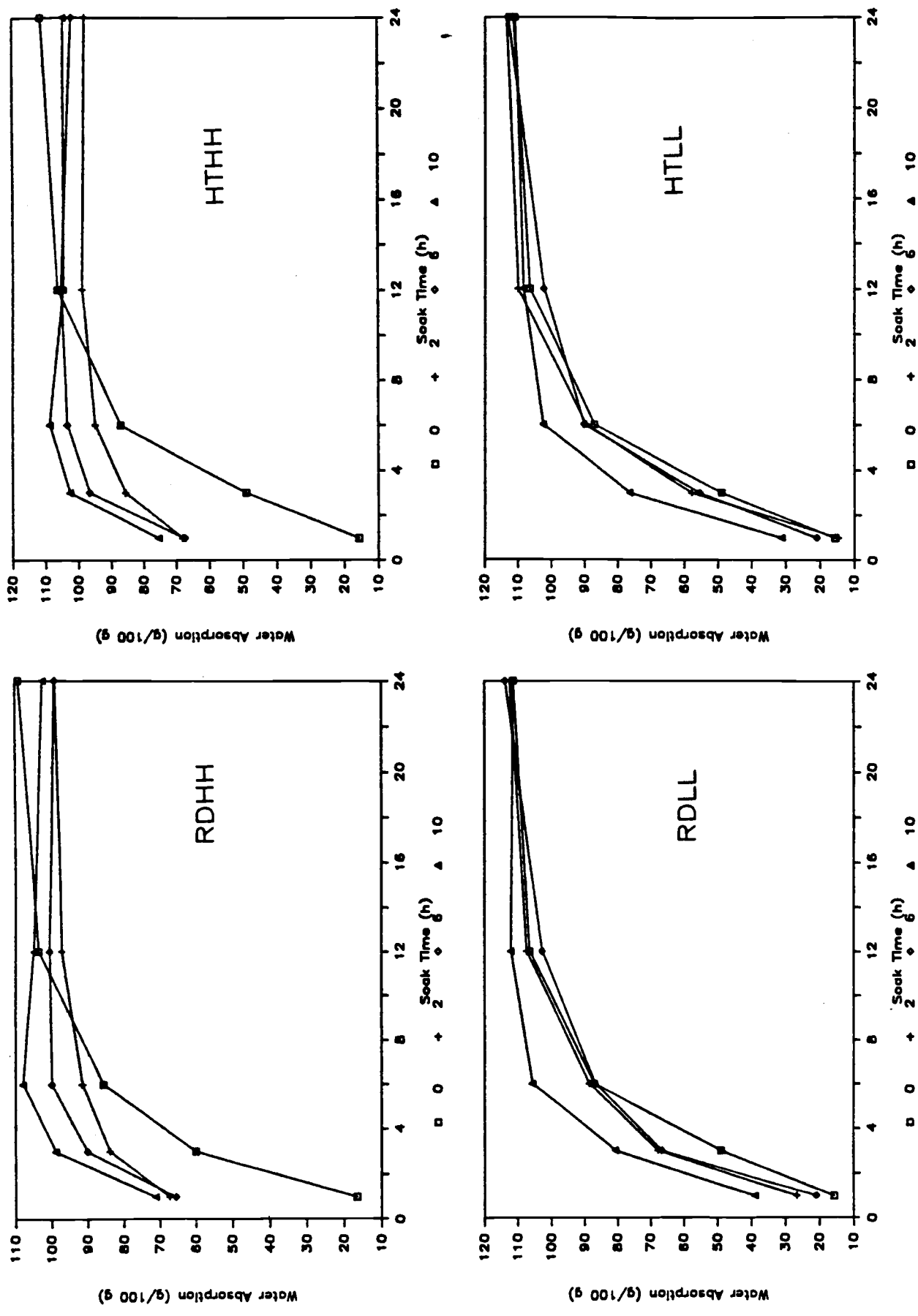
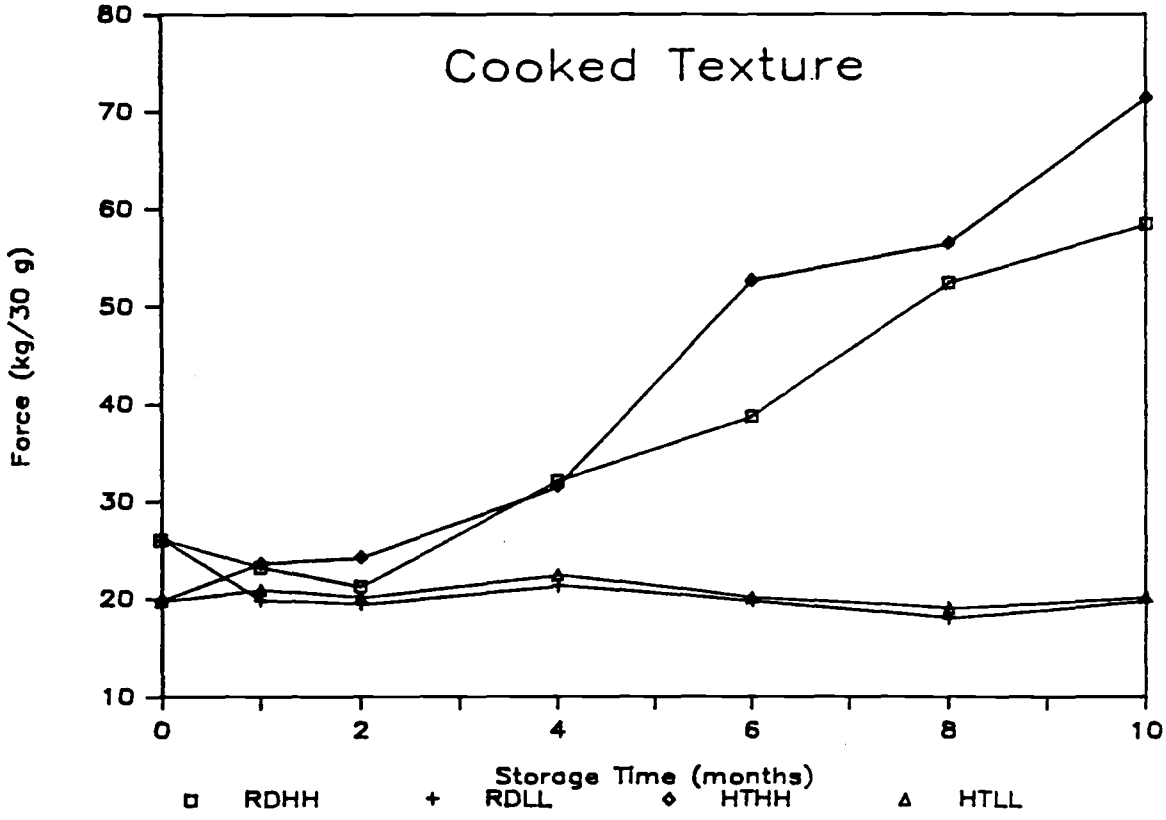

HTHH
HTLL
RDHH
RDLL
Water Absorption (g/100 g)
Soak Time (h)
0
2
6
10

Figure 4


Cooked Texture
Force (kg/30 g)
80
70
60
50
40
30
20
10
0
2
4
6
8
10
Storage Time (months)
RDHH
RDLL
HTHH
HTLL

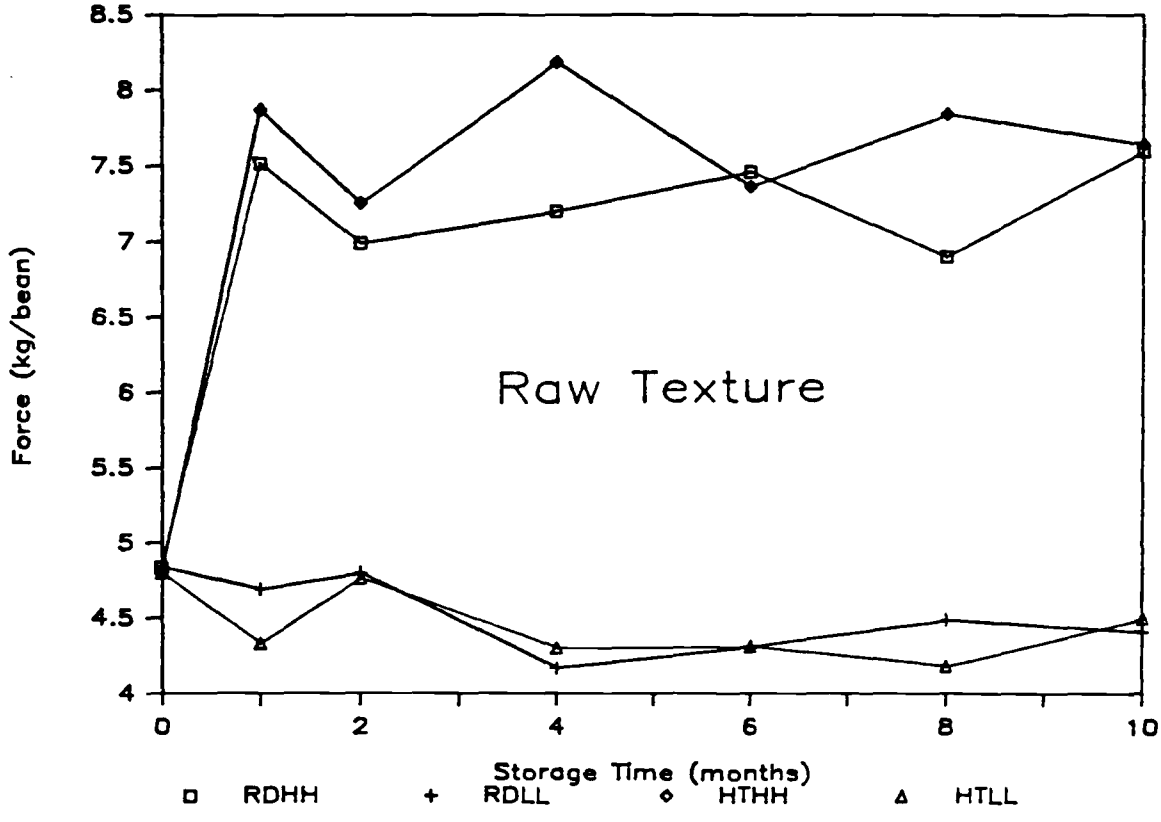

Raw Texture
Force (kg/bean)
8.5
8
7.5
7
6.5
6
5.5
5
4.5
4
0
2
4
6
8
10
Storage Time (months)
RDHH
RDLL
HTHH
HTLL

Figure 5

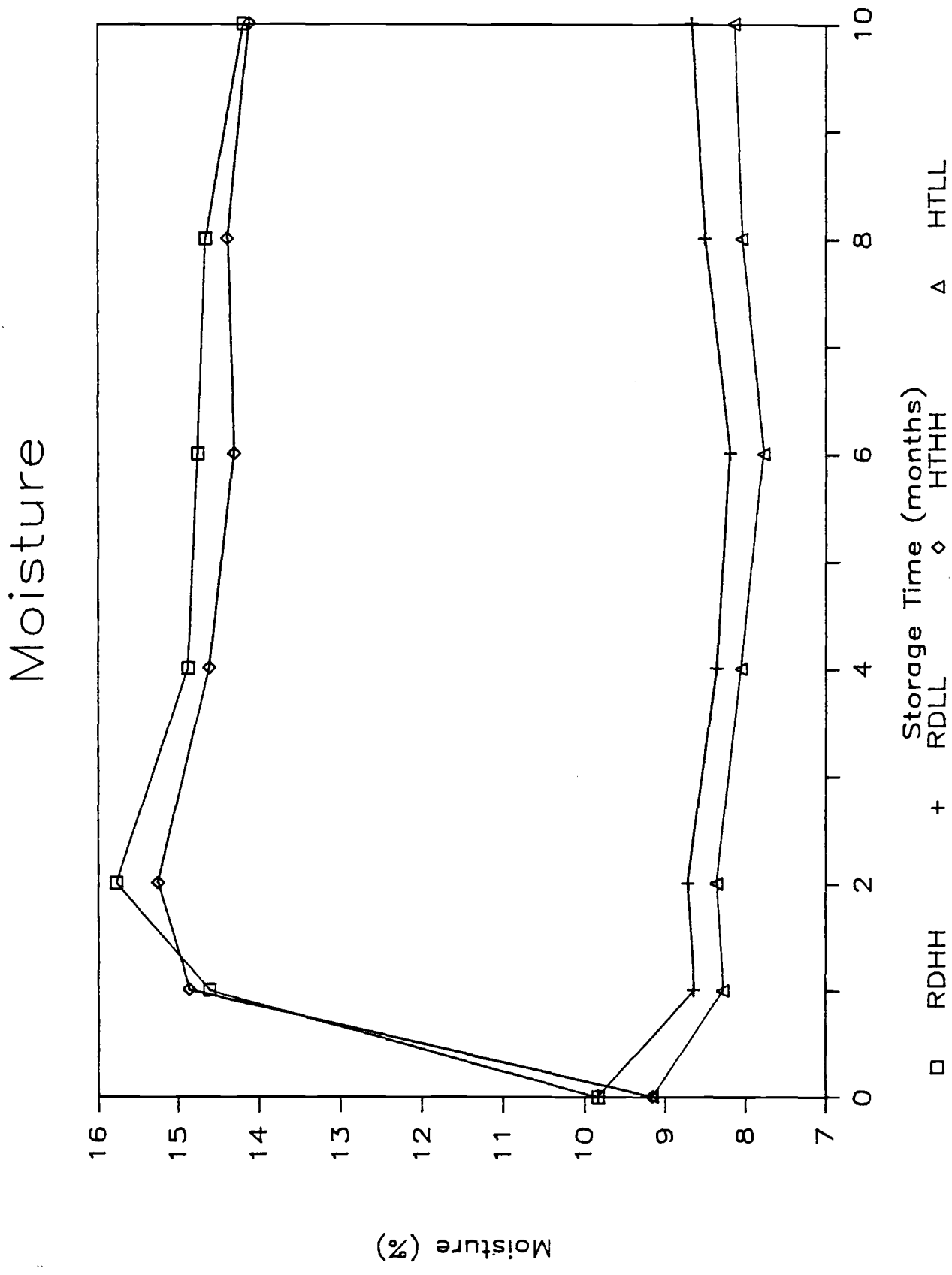
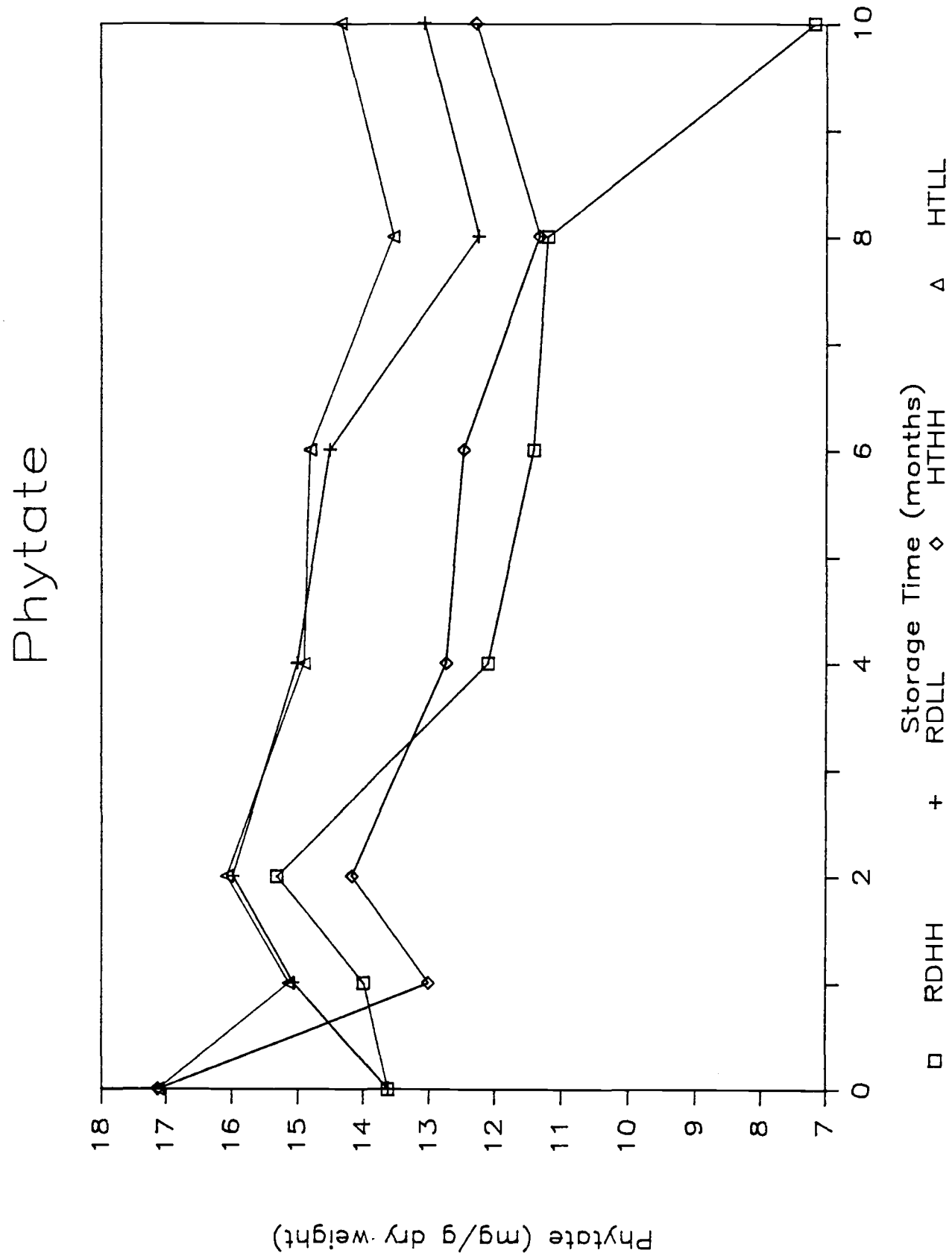

Moisture
Moisture (%)
16
15
14
13
12
11
10
9
8
7
0
2
4
6
8
10
Storage Time (months)
□ RDHH
+ RDLL
◇ HTHH
△ HTLL

Figure 6


Phytate
Phytate (mg/g dry weight)
18
17
16
15
14
13
12
11
10
9
8
7
0
2
4
6
8
10
Storage Time (months)
□ RDHH
+ RDLL
◇ HTHH
△ HTLL

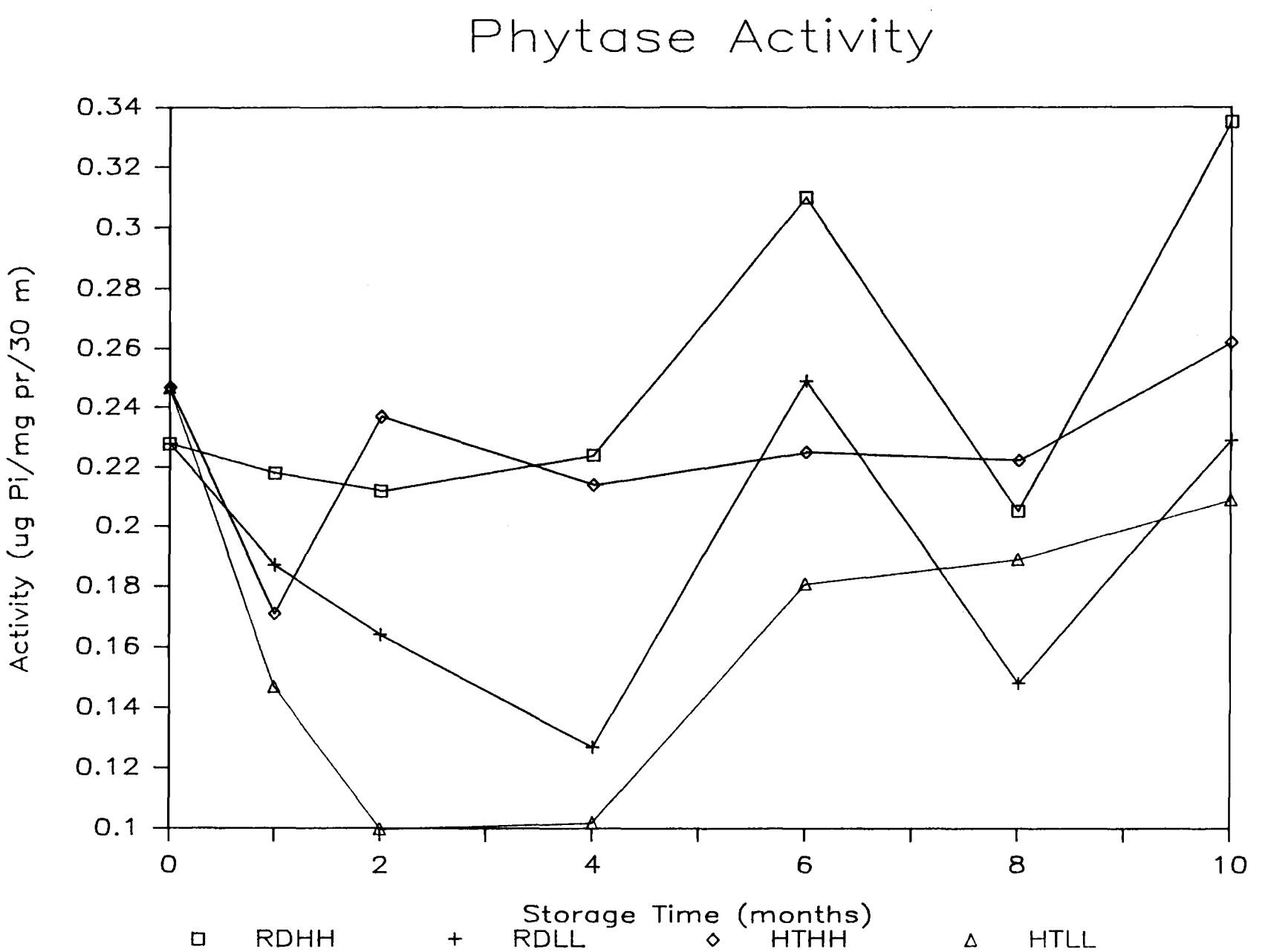

Phytase Activity
Activity (ug Pi/mg pr/30 m)
0.34
0.32
0.3
0.28
0.26
0.24
0.22
0.2
0.18
0.16
0.14
0.12
0.1
0
2
4
6
8
10
Storage Time (months)
RDHH
RDLL
HTHH
HTLL

Figure 7

Figure 8

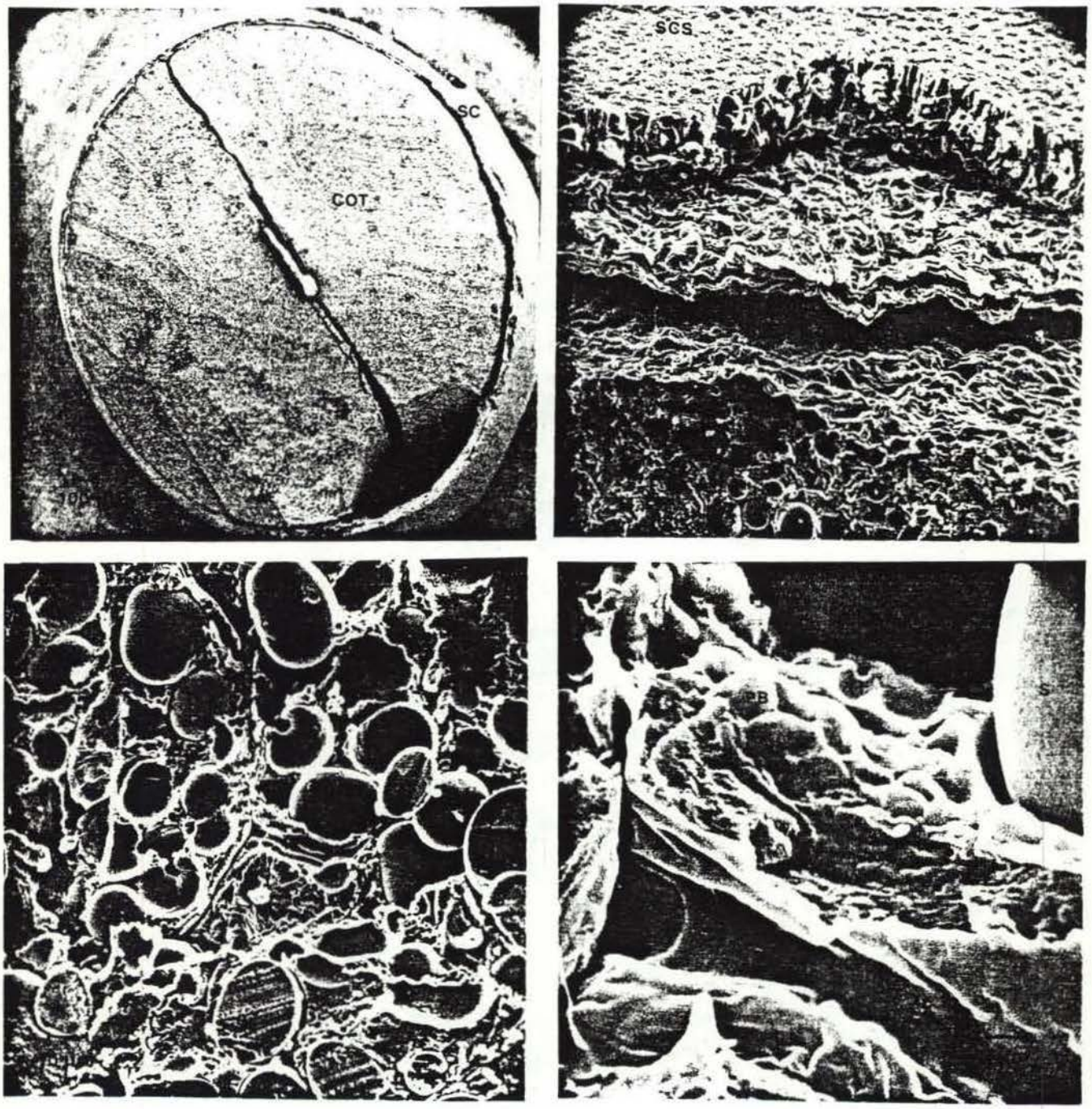
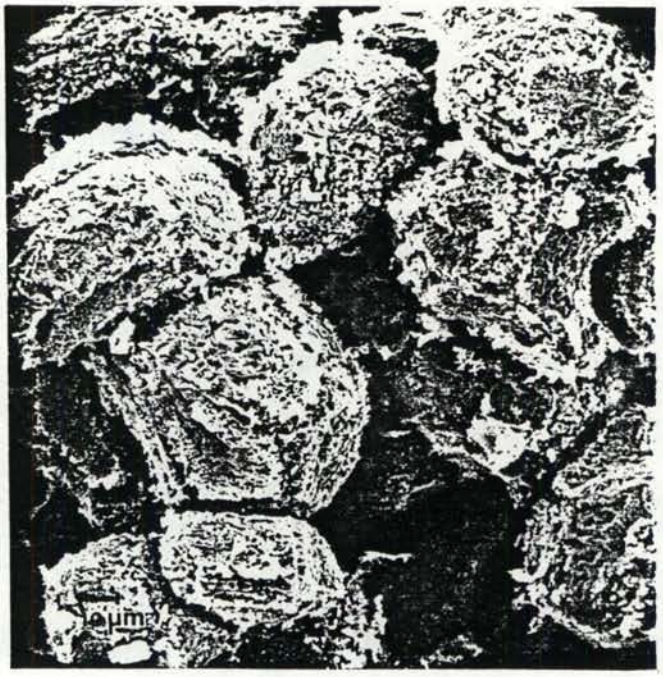


Figure 10

A



B

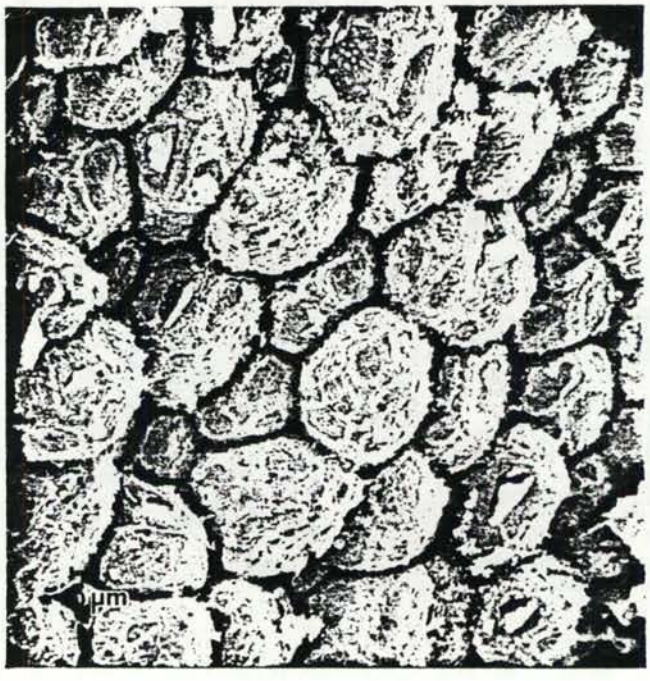
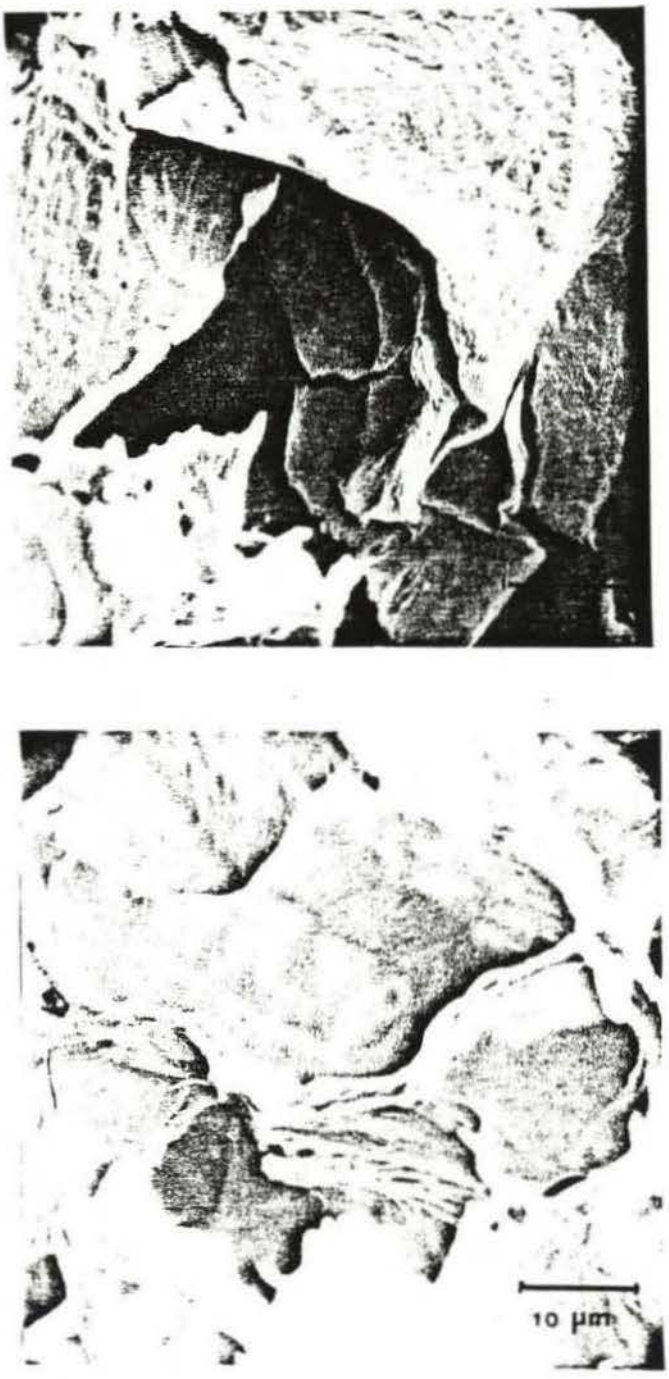


Figure 11



Future Research

Several experiments seem dictated by the preliminary research.

1. A more complete examination of the microstructural differences between the control and hard-to-cook beans of the middle lamella, cell wall and plasmalemma is called for. This would include a correlative study employing light microscopy, scanning electron microscopy (SEM) and transmission electron microscopy (TEM) The localization of lignin would be an important aspect of this study. Histochemical techniques are available for the identification of both pectin (Albersheim and Killias, 1963) and lignin (Hepler et al., 1970) at the electron microscope level. It remains to be seen whether these techniques are sensitive enough to permit positive identification.

X-ray microanalysis to determine mineral content and distribution, specifically that of Ca^{++}, Mg^{++}, K^{+} and Na^{+}, can be used to investigate the divalent/monovalent cationic exchange hypothesis. This technique may also provide evidence of the possible role of protein in the middle lamella (i.e., presence of S) (Varriano-Marston and De Omana, 1978).

2. Differential scanning calorimetry (DSC) is a powerful tool that can be used to study the thermal properties of the intact bean. Research has been performed on separate bean components including protein (Arntfield and Murray, 1981) and starch (Biliaderis et al., 1980; Youssef et al., 1982), and on the interaction of some constituents such as lipid-amylose complexes (Kugimiya et al., 1980; Bulpin et al., 1982). To gain an

understanding of the role of each component it is imperative that the "biological system" be studied. Preliminary thermal curves show that five distinct events take place between 15 and 110°C. To interpret these events it will be necessary to examine each constituent and their interactions, and extrapolate from this model system to the intact bean. It is hoped that this approach will supply information on the differences in cooking characteristics between the hard-to-cook and control beans. DSC may also provide information on hydration characteristics.

Protein and starch fractions can be obtained by air classification (Reichert, 1982). When whole bean tissue is used a cross section of the seed would be preferable. It is essential that samples (approx. 10 mg) be brought to constant moisture values as the temperature at which denaturation/gelatinization occurs is dependant on the moisture content. Samples will be put in hermetically sealed pans and heated from 15 to 150°C at a rate of 10°C/min using a pressurized cell to prevent pans from 'blowing'. Reruns of these samples will be performed after a known cooling cycle.

Texture data on the raw beans indicates that increased force is required to cleave individual samples that have been stored at high temperatures and high humidities though the moisture content is higher than in the controls. This toughening is apparent at one month, after which the force values are relatively constant. Textural differences in the cooked product are not immediately apparent but increase gradually over storage time.

One hypothesis to explain the difference in texture may be the actual distribution of water within the cotyledon tissue. If the water is predominantly intercellular in the high temperature, high humidity (HH) beans, the texture differences could be the result of the increased force required to fracture non-hydrated protein bodies and starch granules. Low temperature, low humidity (LL) beans may have predominantly intracellular water which, in turn, may have a softening influence on the storage components as indicated by lower force values.

The difference in cooked texture may result from minimal restriction to the passage of water inter- to intracellularly during the soaking and cooking processes for the initial stages of storage. As storage time progresses, this movement could be severely restricted and textural toughening would become evident.

If lignification occurs in the beans over storage this hypothesis may be valid, as one of the functions of lignin is to prevent the transport of water across cell walls (Sarkenin and Ludwig, 1971). It has also been observed in light micrographs that the starch granules of HH beans do not appear to be fully gelatinized, possibly a result of lack of hydration.

A possible method to establish the water distribution is that of resistance measurements (Swatland, personal communication). If water were intercellular, resistance would be low (hypothetically HH). If water were intracellular, resistance would be high (hypothetically LL). In the latter case, an initial decrease in the resistance would be expected with higher resistances occuring as the water moved across the cell wall. A

comparative study should be done using both this resistance technique as well as following the water front microscopically.

4. An extension of the phytase/phytate work should be explored. This would entail adding phytase to the soak water to establish whether hardening can be induced, and using EDTA to chelate Ca^{++} and Mg^{++} to see if hard beans can be softened.

Since the middle lamella/cell wall complex is central to this defect it is proposed that this fraction be isolated from both soft and hard beans and differences in structure and composition be examined using SEM, TEM, fluorescent light microscopy and possibly x-ray diffraction. A chemical assay for lignin would also be performed. The response of this fraction to various divalent/monovalent cation ratios and phytase/phytate levels may explain the extent of participation of this mechanism in the hard-to-cook defect. The middle lamella/cell wall fraction can be isolated using a washing and sieving technique (Loh et al.).

5. One method of establishing the contribution of enzyme activity to the hard-to-cook defect is to irradiate the samples to cause total inactivation of enzymes and then monitor them for the defect. This will be done on this years harvest which will be stored as before and tested for development of the hardening phenomenon.

A REVIEW OF TEXTURAL DEFECTS IN COOKED RECONSTITUTED LEGUMES - THE INFLUENCE OF STORAGE AND PROCESSING

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ABSTRACT

Legumes provide an important part of the world's protein requirements, as well as other nutrients, but they are underutilized as food. A major factor limiting expanded consumption is storage induced textural defects that prolong cooking time and demand correspondingly higher energy requirements for preparation. Estimates of losses due to hardening are difficult to obtain but show the economic importance of the problem. These defects, including the hard-to-cook phenomenon and hard shell, are initiated by structural and compositional factors but can be at least partially controlled by storage and processing conditions. The available literature on bean hardening is reviewed from which it may be concluded that adverse storage conditions (high temperatures and humidities) consistently produce these defects. A kinetic approach is taken to the hardening problem, including hydration and cooking, which should allow a better understanding of the processes involved. Methods that can be utilized to produce better cooking legumes are reviewed as are processing alternatives including disruption and dry fractionation, wet fractionation, extrusion, enzymes and animal feeding. The influence of hardening on the nutritive value of legumes, although not extensively studied, is examined and it is concluded that protein quality and the availability of essential amino acids can suffer. A course of action for future research is recommended.

INTRODUCTION

Legume foods have been called "the meat of the poor", suggesting their important role in supplying much needed protein among lower socioeconomic groups. Different areas of the world show a marked preference for a few types of dried legumes as shown in Table 1 and it has been suggested that civilization foci evolved depending on them and nutritionally complementing staple cereals (Sauer, 1969).

Recent population pressures on food availability have been addressed internationally by technological solutions aimed at increasing yields through a more intensive use of agricultural inputs such as irrigation, fertilizers, energy and improved varieties. Indeed, the impact of this "green revolution" on the world production of grains, particularly cereals, has been enormous (Jennings, 1976). The overall effect in developing countries, however, is somewhat blurred by socio-economic problems and by the fact that this larger production enters the same antiquated food pipeline to reach the final consumer. In the case of legumes, increases in production are less spectacular than for cereals and they also face severe postharvest handling problems, the major ones being physical losses and the development of textural

defects during storage including hard-to-cook and hard shell.

A companion article (Stanley and Aguilera, 1985) addressed the influence of structure and composition on textural defects of cooked legumes. The present review emphasizes the much neglected storage and processing aspects as related to quality defects.

POSTHARVEST LOSSES OF LEGUMES

There have been few systematic efforts to determine postharvest losses of plant foods. In the case of grain crops they occur by a combination of three main factors acting in a cummulative manner: a) predation by birds and rodents while the crop is being dried; b) difficulty in achieving effective drying and prevention of moisture pick-up which results in quality losses during storage, and c) a massive problem of insect infestation (McDowell, 1984). The enormous losses resulting from the action of these three vectors would provide more than the annual minimum

caloric requirements of 168 million people (NAS, 1978). Table 2 presents some reported losses of legumes in the developing world, where 60-70% of the stock grain is kept in local storage by farmers or merchants (UNIDO, 1979).

It is practical to separate postharvest losses of dry legumes due to textural defects from those caused by other factors. The former are more difficult to quantify and are rarely reported in the literature. In a recent survey conducted by INCAP in Guatemala, farmers indicated the loss due to seed hardening to be the most significant, affecting between 3.33 and 32.14% of the total production (INCAP, 1983). Insect damage is the major cause of physical loss in pulses (Adams, 1977). Harvested legumes usually carry a field infestation, mainly of bruchid beetle species, which lay their eggs on the maturing pods.

Governments have sustained large economic losses due to postharvest mishandling of beans. In Nicaragua, losses, due mainly to insects, amounted to 5,240 tonnes in 1975, valued at about 2.4 million U.S. dollars (Giles, 1977). In Central America and Panama, beans that developed the hard-to-cook condition during prolonged storage resulted in losses equivalent to 12 million U.S. dollars in 1977 (Gonzalez, 1982). Another documented case occurred

in Guatemala where 5,000 tonnes of beans purchased by the government at US$0.66/kg had to be sold at US$0.15/kg after inadequate handling and storage (Booth, 1980).

HARDENING DURING STORAGE: ANALYTICAL DATA

There are several studies presenting quantitative data on the effect of storage on bean hardening. Three main aspects make analysis of this information difficult: a) the fundamental parameters describing storage conditions, such as moisture content of the beans, temperature and relative humidity of the environment, are not adequately reported for the whole period; b) the protocol for sample preparation and cooking varies in terms of the steps followed, level of the process parameters, age of the beans, instrumentation used, etc.; c) textural deterioration of beans with time is evaluated by widely different methodologies ranging from "cooking times" at different pressures to "hardness", represented by the maximum force detected by instrumental means.

The data available, however, are consistent in demonstrating that hardening of beans under adverse storage conditions is a pervasive phenomenon. Figure 1 summarizes information reported in four studies for black beans stored at around 12% moisture and at 25°C. In order to make

comparisons, relative hardness has been defined as either the maximum force or the cooking time at any time divided by the value at the begining of the study. In spite of all the methodological differences discussed before, the data follow a trend that could be represented by a zero (N=0) or first (N=1) order reaction. Thus, after 10 months of storage at these relatively mild conditions, beans would require a 60% longer cooking time to soften and approximately an equal amount of extra fuel. Under severe but nevertheless real storage conditions such as those in the tropics, hardening becomes uncontrollable. Antunes and Sgarbieri (1979) reported that beans with initial cooking times of 60 min could not be softened/even after 300 min when stored for six months at 37°C and 76% R.H. Similar results /have been reported by Muneta (1964) / and Luse (1982) among others.

High moisture content in beans greatly accelerates hardening, particularly when it is in excess of a /certain critical value. The early work of Morris and Wood (1956) reported practically no change in flavor, lipid acidity and texture in beans stored for 2 years at 25°C and below 10% moisture. However, the rate of deterioration increased almost exponentially above a moisture level of 10-11%, corresponding to a water activity of 0.3 to 0.45. Acker (1969) and others have demonstrated that enzymatic activity

(e.g., lipase) is restricted at a_w's below 0.3 and that at higher values it parallels the sorption isotherm. Figure 2 summarizes the relationship found between a typical moisture isotherm for beans and deterioration processes of enzymatic (lipid acidity), physical (texture) and microbiological activity. Much further research is needed to fully disclose the relationships between the rates of deterioration and the sorption isotherm since dry beans are stored at reduced water activities. This should provide an insight into the relative importance of different mechanisms and a basis to predict losses during storage.

Several studies seem to agree that at refrigeration temperatures (0-5°C) minimal changes in hardness occur (Molina et al., 1976; Moscoso, 1982). Storage in the range of 12-20°C also induces only minor alterations in texture (Burr et al., 1968; Luse, 1982; Gonzalez, 1982). For example, in the work of Antunes and Sgarbieri (1979) beans stored at 12°C and 52% R.H. showed practically no change in hardness during the first six months.

All information available indicates that impairment in the cooking quality of beans may be overcome

by artificially drying beans to a safe moisture level and subsequently preventing moisture pickup and/or by using refrigeration. In the case of tropical countries the first alternative is the only practical one worthwhile of being considered.

HARDENING DURING STORAGE: A KINETIC APPROACH

From an engineering viewpoint the study of quality changes in beans during storage should be aimed at generating a model that predicts or simulates the phenomenon under various conditions. Modeling has been successfully used in food processing and storage (Lund, 1983a; Karel, 1983) and to predict physical changes (Lund, 1983b). A preview of the potential of a kinetic model as applied to beans is illustrated using the data of Burr *et al*. (1968). These authors reported changes in cooking times of pinto and large lima beans at three temperatures (4, 12 and 21°C) and different moistures ranging from 8.9 to 16%. By assuming a zero order reaction model, a reaction rate constant (k) can be calculated from:

$$\frac{d\theta}{dt} = k$$

where θ = cooking time at observed time (min)

t = storage time (months)

k = reaction rate constant

This model implies that the rate of loss in quality (longer cooking times) is constant with storage time and independent of the hardness of the bean at any time. A graph of storage time vs cooking time should be a straight line with slope equal to k. Figure 3, for lima beans, shows that k is a function of moisture content and temperature. Hence, changes in cooking time may be more accurately predicted by a model such as:

$$\frac{d\theta}{dt} = k_o\ (W)\ e\ ex\ P(-E_a W/RT)$$

where

k_o = a factor that depends on the moisture content

W = moisture content, %

E_a = energy of activation, kcal/mole

R = molar gas constant, 1.987 cal(°K mole)

T = absolute temperature, °K

The actual model describing the data of Burr et al. (1968) is:

$$\ln\left[\frac{(\theta_f - \theta_o)}{t}\right] = (0.5181\ W - 6.6391) + (1.0505\ W - 26.26)(1000/T - 3.401)$$

where θ_o and θ_f are the cooking times at the beginning and at any storage time t, respectively. Lines in Figure 3 represent the cooking times as predicted by this model.

Except for the cases of 14.9 and 15.5% moisture at 21°C all predicted values fall within 10% of the experimental data. The model is also accurate in simulating hardening for the first twelve months for all moisture contents and temperatures. A higher order relationship between E_a and W would provide for an even better fit. Important applications of this type of model are in accelerated storage tests and to predict cooking times under unsteady storage conditions (Labuza and Kamman, 1983).

The energies of activation calculated from this model vary between 18.7 and 27.0 kcal/mole in the moisture range of 16.0 to 12.0%. Reactions involving losses in texture and flavor as well as those of enzymatic origin have E_a's in the range of 10-30 kcal/mole (Labuza, 1972), which further supports the hypothesis of an enzymatic component in the hard-to-cook phenomena.

KINETICS OF HYDRATION AND COOKING

Preparation of legumes for eating involves hydration followed by cooking. The dramatic physical changes that occur can sometimes be adequately described by chemical kinetic models (Lund, 1983b). A study by Loh and Breene (1982) showed a first-order model to be adequate in

describing textural changes during heating.

Quast and da Silva (1977b) found that the semi-logarithmic graphs of hydration time vs temperature for black beans were not straight lines, with z values varying between 40-200°C. Similar experiments performed by Kon (1979) with small white beans and Kubota (1979) with red beans resulted in sigmoid-shaped curves when a dimensionless soaking ratio was plotted against time. The apparent activation energies were in the order of 10 kcal/mole which confirmed that hydration by soaking is controlled by the diffusion process.

There seems to be some confusion regarding the kinetics of legume cooking. Quast and da Silva (1977a) and Silva et al. (1981) found that semilogarithmic plots of texture (force) versus cooking time for black beans were not straight lines as required by first order kinetics. Sefa-Dedeh et al. (1978) and Sefa-Dedeh and Stanley (1979) working with cowpeas concluded that the rate of cooking for the time during which the middle lamella was visibly softening (up to 45 min at 100°C) followed first order kinetics. This holds true also for the former data during an initial period after which the cooking reaction tends to become order zero. The temperature dependence of the

cooking rates for water-soaked black beans had activation energies between 31.3 and 35.5 kcal/mole. High activation energies and changes in reaction order with time are also characteristic of starch gelatinization (Lund, 1984). Thus, it may be postulated that cooking of beans comprises at least two phases: an initial phase characterized by middle lamella breakdown and cell separation that follows first order kinetics and a second phase where the predominant phenomenon is gelatinization of the starch granules inside the cells. This is in agreement with findings of Hahn et al. (1977) who reported that cell separation in water soaked beans occurred at about 76°C which was also the onset of intracellular starch gelatinization as followed by loss of birefringence. When degree of gelatinization as determined by chemical methods is used as a measure of doneness, full gelatinization required 90 min at 100°C in the case of soaked rough rice (Bakshi and Singh, 1980).

A more thorough study on the kinetics of bean cooking and the interrelation between physical and chemical parameters and organoleptic properties should be highly rewarding in terms of the understanding the mechanism of hardening and also calculation of the energy savings that could be derived.

PROCESSES TO IMPROVE STORAGE STABILITY

The methods utilized to produce better cooking

legumes and to control or overcome the development of textural defects seem to have as their bases either a reversal of the phytate-cation mechanism or the inactivation of enzymatic activity, phytase or otherwise (Stanley and Aguilera, 1985). For convenience, these techniques will be mainly grouped according to the operations involved. Also included are several processes that produce undesirable effects.

Heat

The use of heat is a common method to inactivate enzymatic activity in foods. Molina et al. (1976) employed this approach in developing a process to reduce textural defects in stored black beans. When samples were treated by retorting or by heating under atmospheric steam, it was found that hardness was retarded during 9 months of storage at 25°C/70% RH. As well, the heat treatment exerted a beneficial influence on water absorption capacity of the beans but this was not correlated to hardness. It is of importance to note that although moist heat treatments succeeded in reducing hardness relative to an unheated control, all the treatments hardened during storage when compared to a heated sample kept at 4°C. The more severe the heating treatment, the more hardening occurred. Another most interesting finding in this study was that elevated

storage conditions produced a noticeable increase in lignified protein that paralleled closely (r = 0.91) the development of hardening. Heat treatment slightly reduced lignification in the cotyledons but not in the seed coat, however, none of these values were close to the much lower results obtained for samples stored at 4°C. It should also be noted that the intensity of cotyledon color decreased as lignified protein increased, implicating polyphenols in this reaction. Thus, in higly colored beans, if enzymatic reactions, presumably phytase, are eliminated by heat a delay in hardening will be seen but lignification still takes places that is highly correlated with the degree this defect finally attains.

Dry heat has also been used to overcome the development of hardness during storage. Aguilera et al. (1982) demonstrated that dry heat processing using ceramic beads as a transfer medium allowed the continous, large-scale roasting of beans. Subsequently, Aguilera and Steinsapir (1985) placed recently harvested Chilean gray beans in an externally heated metal drum for 3 min by which time the sample had reached an internal temperature of 105°C. Following 10 months storage at 22°C, cooked heated beans were statistically significantly, but mathematically slightly, more tender than an unheated

control (397 g for the control versus 345 for HTST, as measured by the puncture test).

It will be noted in these data that a brief heat treatment produced an immediate increase in hardness. This may be a consequence of thermal activation of phytase (Chang et al., 1977) or, perhaps, case hardening with a concomitant reduction in water imbibition. On the other hand, the HTST process yielded an immediate decrease in hardness. The reason for this is not known but since a heat treatment had been applied and no storage effect is involved, it is unlikely to be enzymatic in nature. Perhaps partial starch gelatinization or other processes, physical in nature, are responsible. Finally, and most importantly, it will be observed that even though the HTST treatment significantly reduced the development of hardness relative to an unheated control, 10 months storage produced a large degree of hardness in beans that had been so severely heat treated that only 2.5% would germinate. These data, if it is assumed that the samples contained no active enzymes, points strongly to a nonenzymatic component to bean hardening. If the experiments of Molina et al. (1976) are taken into account, a process of nonenzymatic lignification could explain these results.

Dry roasting using hot particulate media has advantages that are beneficial to stored beans. Roasting removes moisture to levels 2 to 4 percentage points below the equilibrium moisture attained by solar drying (Aguilera et al., 1982; Mittal et al., 1983). It also can be used for pasteurizing slightly infested or mold contaminated grains and reclaiming them for human consumption (Mittal et al., 1981; Aguilera and Steinsapir, 1985).

Irradiation

Irradiation has been considered as a means of reducing the cooking time for dehydrated vegetables. Doses for a tenfold reduction in cooking time in legumes varied from 2.0 to 4.0 Mrad (FAO/IAEA, 1970). Sreenivasan (1974) and Nene et al. (1975) examined the potential of radiation processing to improve texture, hydration and cooking quality of legumes. A reduction in cooking time of about 40% was observed in red gram when irradiated at 1 Mrad dose. This was accompanied by higher solubility and increased swelling power of the irradiated starch and enhanced protein digestibility.

The Chilean authors also examined the

influence of irradiation on preventing hardness during storage. Treatments of 10, 50 and 100 krad were employed and although irradiated samples generally had lower hardness values than the control, there was no clear relationship between irradiation dosage and texture. This may have resulted from the use of levels lower than those normally administered to produce enzyme inactivation (Aguilera and Steinsaper, 1985).

Soaking

It is known that phytate can be removed from whole dry beans by diffusion and associated enzymatic hydrolysis through soaking. Chang et al. (1977) found that incubation of presoaked beans in water at 60°C for 10 hours lowered the phytate content by 90% by way of both mechanisms. Although this study did not include textural measurements, it is to be expected that a hardening effect would result from such a treatment. Similarly, Mattson (1946) observed that soaking or leaching of peas rendered them uncookable. Thus, although removal of phytate may improve nutritional value of beans, it also would produce the undesirable consequence of increased hardness.

Freezing

The former authors also experienced a 20% increase in phytate hydrolysis when beans were frozen

before soaking. It is suggested that the formation of ice crystals during freezing ruptured membranes allowing enzyme substrate contact (Chang et al., 1977).

Chelation

According to the phytate-cation theory, any process that removed divalent cations or supplants them with monovalent ones would be beneficial to texture. That this is, in fact, effective is seen in the work of Rockland and Metzler (1967) who demonstrated the ability of tripolyphosphate and EDTA to reduce hardening. By the same token, the addition of divalent cations such as Ca^{++} will increase cooking time (Al-Nouri and Siddiqi, 1982 ; Jones and Boulter, 1983).

"Quick cooking" beans

The pioneering work of Louis Rockland resulted in the advancement of a protocol capable of reducing cooking time of various legume varieties by 80% or more. This procedure, termed "quick cooking" represents a successful application of the principles illucidated by Mattson. Figure 4 shows a flow sheet that outlines this technology which is basically a vacuum infiltration of monovalent phosphate and other salts followed by drying (Rockland, 1978). It is interesting to note that the hydration medium was

selected both on the basis of ability to disperse and solubilize protein and to chelate divalent cation-protein complexes. Further work on the mechanism of this approach by Varriano-Marston and de Omana (1979) led to the conclusion that the effect is produced by ion exchange and, possibly, chelation. Divalent cations that stabilize pectates are replaced by monovalent ions or removed by chelation to phosphate groups. Silva et al. (1981) reported that water absorption was not significantly influenced by the mixed salts in the soaking water but cooking times were reduced for several legume species. This technique has been applied to most common types of dry beans, most recently to broad beans (Al-Nouri and Siddiqi, 1982).

PROCESSING ALTERNATIVES FOR HARD BEANS

Alternative processes for dry beans depend basically on the demand for the products and on the technological level that can be afforded. Most processes presented below have not been implemented at an industrial level nor have the technologies described been applied to hard beans, nevertheless, they are options to be explored for up-grading their value.

Disruption and dry fractionation

It is a widely appreciated principle of food

science that tough or hard commodities may be rendered acceptable by desintegration and/or cellular disruption, viz. the production of comminuted meat products from tougher cuts. This same approach has been taken with dried legumes. In some regions of the world, particularly in the Far East, legumes are dry milled to remove the seed coat leaving the split cotyledons (dhal). A method for preparing instant bean powders in which cell rupture was kept to a minimum is described by Bakker et al. (1973). Peas, beans or lentils were soaked, cooked, ground and drum or spray dried to remove excess moisture. Reconstitution properties were good since minimal free starch liberation occurred due to controlled cell rupture.

Dry milling causes extensive intracellular damage and has been exploited to liberate starch granules and proteinaceous material in beans, (Kon et al., 1977) field peas and horsebeans (Vose et al., 1976). For example, Aguilera et al. (1982) have produced bean flours by roasting, pin milling and air classification with high protein contents (about 50%) but reduced trypsin inhibitor and hemagglutinin content. This flour can be further fractionated by air classification into a cereal analog stream (16% protein) and soy flour analog stream (43% protein); the former ingredient could be used as a replacement for wheat flour while applications for the

latter include extruded products and as a protein fortificant The principle has been implemented commercially by Pro-Star Mills Ltd. in Canada which built a 5,000 ton/year plant to fractionate pea flour into starch (two-thirds) and protein concentrate (one-third, 60% protein, dry basis) (Annonymous, 1975). Thus, one way to utilize beans with textural defects is to employ further processing to yield useful products in which texture is not a determinant of quality.

Wet fractionation

Separation of starch and protein from seeds using aqueous media is accomplished by wet milling, centrifugation of the insoluble starch granules and precipitation of the protein from the supernatant or sieving. Such wet fractionation techniques have been applied to chick pea (Deschamps, 1958), field pea and fababean (Youngs, 1975). In this latter case either a 90% (dry basis) protein isolate from fababean or a 63% concentrate from field pea were obtained at pilot plant scale, depending on the amount of washing. The evaporation of large quantities of water and major effluent problems are the main drawbacks of wet processing. (A similar process has also been commercialized in Canada (Woodstone Foods, Portage La Prairie, Manitoba)).

Extrusion

In most parts of the world legume foods are

prepared from whole beans or splits (dhal). They may also be consumed roasted, fried, germinated or as powders in soups. Where texture is a desirable attribute whole bean powders or fractions may be structured using a combination of shear, heat and pressure. The most common method of "texturization" is extrusion-cooking (Harper, 1981). Molina et al. (1982) used a low cost Brady Crop Cooker to precook and form flours from black beans hardened during storage. Maximum gelatinization was achieved when beans were previously soaked in a 1% NaCl/0.75 $NaHCO_3$ salt solution. Aguilera et al. (1984a) reported that extrusion-texturized vegetable proteins obtained by substituting bean protein for defatted soy flour at levels of 10, 20 and 30% had similar properties as the 100% texturized soy. However, actual use of texturized bean concentrates as meat substitutes may require further improvements in functionality (Patel et al., 1980). Similar attempts are being carried out in Europe using field bean concentrate (Jeunink and Cheftel, 1979).

Enzymes

Presumably because of the cost and potential impracticability of enzyme treatment, little work has been reported in this area. However, in 1961, Bode used an

unnamed enzyme, possibly either a pancreatin or a microbial amylase, to partially convert starch to dextrins and maltose in green peas. The enzyme was added in brine and a holding period employed prior to retorting. An increase in both tenderness and flavor was reported. Purified cellulase and fungal extracts containing cellulase and/or pectin enzyme, when used in overnight soaks, decreased cooking time of legumes considerably (Morris and Seifert, 1961). Much more recently, an East German patent was issued to cover the use of pectin lyase as a soaking adjunct (Bock et al., 1983). This process is claimed to reduce cooking time and improve sensory quality. The mechanism of this enzyme, not normally found in healthy plant tissue, is to cleave methyl-exterified D-galacturonans (pectin) between residues (Schwimmer, 1981).

Animal feeding

Secondary products of bean production are culls and hard beans. Cull dry beans consist of split, small and damaged seeds collected at harvest that are unsuitable for human consumption. Together with inedible hard-to-cook beans they may find application, after cooking, in animal nutrition as milk replacers for calves (Bell, 1973), for swine feeding (Shimada, 1973) and to fatten livestock and sheep (Kay, 1979). Cooked beans, either autoclaved or extruded, have also been used in poultry diets (Cuca, 1973; McGinnis and Capella, 1973; Myer et al., 1982).

EFFECT OF STORAGE AND PROCESSING ON NUTRITIVE VALUE

Sgarbieri and Whitaker (1982) have recently reviewed the nutritional properties of common bean proteins and the reader is referred to this work as well as to other reports for further information on this general subject (Aykroyd and Doughty, 1964; Jaffe, 1973; Bressani and Elias, 1974).

The effect of hardening and processing on the nutritive value of legumes has not been extensively studied. Legumes are cooked not only to develop proper texture but also to inactivate the heat-labile anti-nutritional factors present in the seed. Studies carried out at INCAP demonstrated that excessive cooking, however, resulted in a lower protein quality as shown in Figure 5a. The initial rise in protein efficiency ratio (PER) is due to the rapid inactivation of typsin inhibitors, hemagglutinins and other antinutritional factors during wet cooking (Liener, 1979). After the optimum PER was reached at about 30-40 min, complex reactions between essential amino acids and carbohydrates or phenolic-type pigments begin to reduce the digestibility of the protein (Bressani, 1982). Over a 20% reduction in available lysine had occurred after 2 hr of atmospheric cooking (Almas and Bender, 1980) or 10 min of pressure cooking (Bressani *et al.*, 1963). Figure 5b shows that the nutritive value of

beans continued to deteriorate during storage while the inverse relationship between cooking time and PER value was maintained (Molina et al., 1975).

The influence of storage on simultaneous changes in hardness and nutritional parameters can be appreciated in the work of Antunes and Sgarbieri (1979).

Table 3, adapted from this work, shows that

a combination of high temperature and high relative humidity not only had a severe effect on the rate of hardening, as discussed previously, but also lowered significantly the protein quality and the availability of essential amino acids. Even after only 6 months of storage at what could be considered benign weather conditions for the tropics (25°, 70-80% RH), the PER of beans was reduced to about 40% the original value and the available lysine, essential for complementing lysine-defficient cereal foods, suffered a 20% loss. A somewhat contradictory result was previously reported by Molina et al. (1975) in which the PER of black beans decreased proportionally to storage time but total methionine and available lysine increased.

Insect infestation can also cause reduction in the nutritional value of stored legumes and make them

unhygenic. For example, infested split chickpeas and pigeon peas had only 80% of the PER of uninfested samples (Parpia, 1972).

Information about the effect that processing alternatives previously presented have on nutritive properties of bean products is also scant. Liener et al. (1976) compared the PER and digestibility of navy bean powders that had been roasted or autoclaved under optimal conditions (15 min at 121°C). The autoclaved powder (PER= 1.69) was nutritionally inferior to the roasted product (PER=1.92) possibly due to the somewhat better protein digestibility shown by the roasted bean. Similar results were obtained by Carvalho et al. (1977) who analyzed instant navy bean powders prepared by roasting in a bed of salt at 190°C for 20 seg or 220 °C for 10 sec followed by grinding. Roasted samples, having 70-80% of the antitrypsin activity originally present, showed higher relative protein values and were more responsive to methionine supplementation than an autoclaved sample. These benefical effects of dry roasting on nutritional quality were also seen in gray beans (Steinsapir et al., 1984) and cowpeas (Sales et al., 1984).

Dry roasting by particle-to-particle heat

transfer can be effectively used for inactivating anti-nutritional factors in whole grains. Short time roasting (1 to 2 min) resulted in a semi-log destruction of anti-trypsin factors within the temperature range of 92-126°C and the inactivation correlated well with reduction in nitrogen solubility (Aguilera et al., 1982). These findings are very timely in view of recent research in which lectin (hemagglutinin) activity has been detected in improperly cooked beans and even in processed legume foods. Korte (1972) reported that residual lectin activity was found in 22% of bean and maize mixtures prepared and cooked under African village conditions, resulting in signs of toxicity. More recently, increases in outbreaks of poisoning by uncooked red kidney seeds involving 870 persons were described in the UK (Gilbert, 1983). Apparently some anti-nutritional factors present in beans may require heat treatment beyond that supplied for softening by conventional cooking.

Quick-cooking beans requiring five to six times less cooking time than regular, water-soaked beans gave similar PER values, ranging from 1.2 to 1.5 (Rockland et al., 1973). It should be noted that a report has suggested that reduced cooking times may lower digestibility and fail to destroy all antinutritional factors (Ekpenyong and

Borchers, 1980) but this has been disputed (Rockland, 1978).

In the area of nutritional properties of stored legumes more systematic data are needed on the effect of each spoilage vector. Further work is required on the kinetics of inactivation of antinutritional factors by heat and of nutritional losses during storage.

CONCLUSIONS

1. The hardening of legumes during adverse storage is a pervasive phenomenon which has economic and nutritional consequences amongst some of the poorer people in the world.

2. The mechanisms responsible for this defect are poorly understood but they might have an enzymatic and a non-enzymatic component.

3. High temperatures and humidities accelerate the process. Hence, while the biochemical mechanisms are being ellucidated, empirical kinetic studies can be used to predict hardening under various conditions and to devise accelerated storage tests for new processes.

4. In the short term most of the efforts in postharvest handling of beans and other legumes should be concentrated in generating recommendations for small farmers and government officials that minimize storage losses. These should include ways to physically protect beans from insects and textural changes by controlled heating, drying, packaging, etc.

5. In the long term further studies should be performed on the utilization of damaged legumes, the effect of processing and storage on the nutritive value and the kinetics of cooking, processing and storage. This information could then be used to maximize the utilization of the legume production around the world while minimizing physical and quality losses and energy consumption.

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FIGURE LEGENDS

Figure 1 Relative hardness (hardness at any time/hardness at time zero) of black beans stored around 12% moisture and 25°C. N is the reaction order of the fitted kinetics.

Figure 2 Representation of the sorption isotherm and stability map for beans after prolonged storage.

Figure 3 Zero order kinetic modeling of the data of Burr et al. (1968). Solid lines represent the values predicted by the model.

Figure 4 Flowsheet for preparation of quick-cooking beans. Source: Rockland (1978).

Figure 5 A) Effect of atmospheric cooking time on the protein efficiency ratio (PER) of black beans Source: Bressani et al. (1963); B) Effect of storage time and pressure cooking time on the PER of black beans. Source: Molina et al. (1975).

TABLE 1. Preferred legumes in different areas of the world.

Area	Legume
Europe	Dry beans (*Phaseolus vulgaris*), dry peas (*Pisum sativum*), dry broad beans (*Vicia faba*).
North America	Dry beans
Latin America	Dry beans
Near East	Dry broad beans, Lentils (*Lens culinaris*)
Far East	Dry beans, chickpeas (*Cicer arietinum*), pigeon peas (*Cajanus cajan*)
Africa	Dry beans, cowpeas (*Vigna unguiculata*)

TABLE 2. Reported losses of selected legumes within the postharvest system.

Country	Total Weight Loss (Percent)	Reported National Production ('000 Tonnes)	Remarks
Ghana	7-45	11	Shelled beans, 1-5 months; unshelled beans, 22
Nigeria	5.4	932	Cowpeas
	1-2		Cowpeas stored 3 months in shell
	20[a]		Cowpeas
Kenya	30	280	On-farm storage
Zambia	40	600	Cowpeas
India	8.5	12,956	Pulses, central storage
Indonesia	5	900	Unspecified storage
Pakistan	5-10	785	Pulses
Belize	20-50	1	Kidney beans, on-farm storage
Brazil	15-25	1,923	Dry beans
Costa Rica	24		Dry beans
Honduras	20-50	48	Dry beans, on-farm storage
Nicaragua	10-35	54	Dry beans

Source: NAS (1978)

UNIDO (1979)

TABLE 3 Effect of time and storage conditions on hardness/nutritional quality of dry beans.

	Storage conditions				
		25°C, 70-80% RH		37°C, 76% RH	
Storage time (months)	0	3	6	3	6
Cooking time (min)	60	85	105	180	300
Hardness (kg)	200	290	315	400	500+
PER	1.01	0.75	0.43	0.21	0.10
Digestibility (%)	62.4	61.9	57.1	59.7	54.4
Available methionine (%)	46.3	41.5	38.2	36.6	27.6
Available lysine (%)	51.6	45.8	43.0	42.0	30.1

Adapted from Antunes and Sgarbieri (1979).

Figure 1

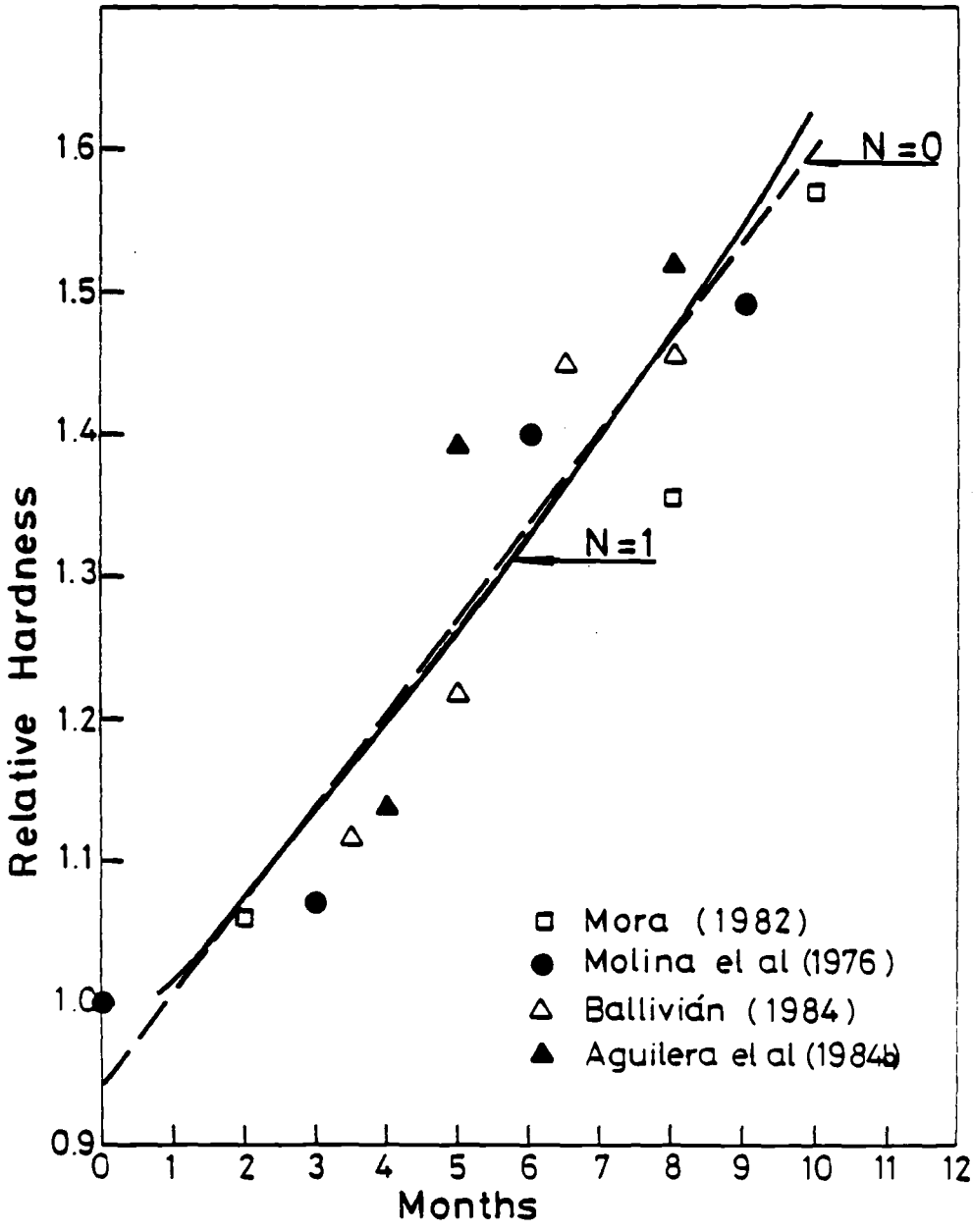

Relative Hardness
Months
N=0
N=1
Mora (1982)
Molina el al (1976)
Ballivián (1984)
Aguilera el al (1984b)
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
0
1
2
3
4
5
6
7
8
9
10
11
12

Figure 2

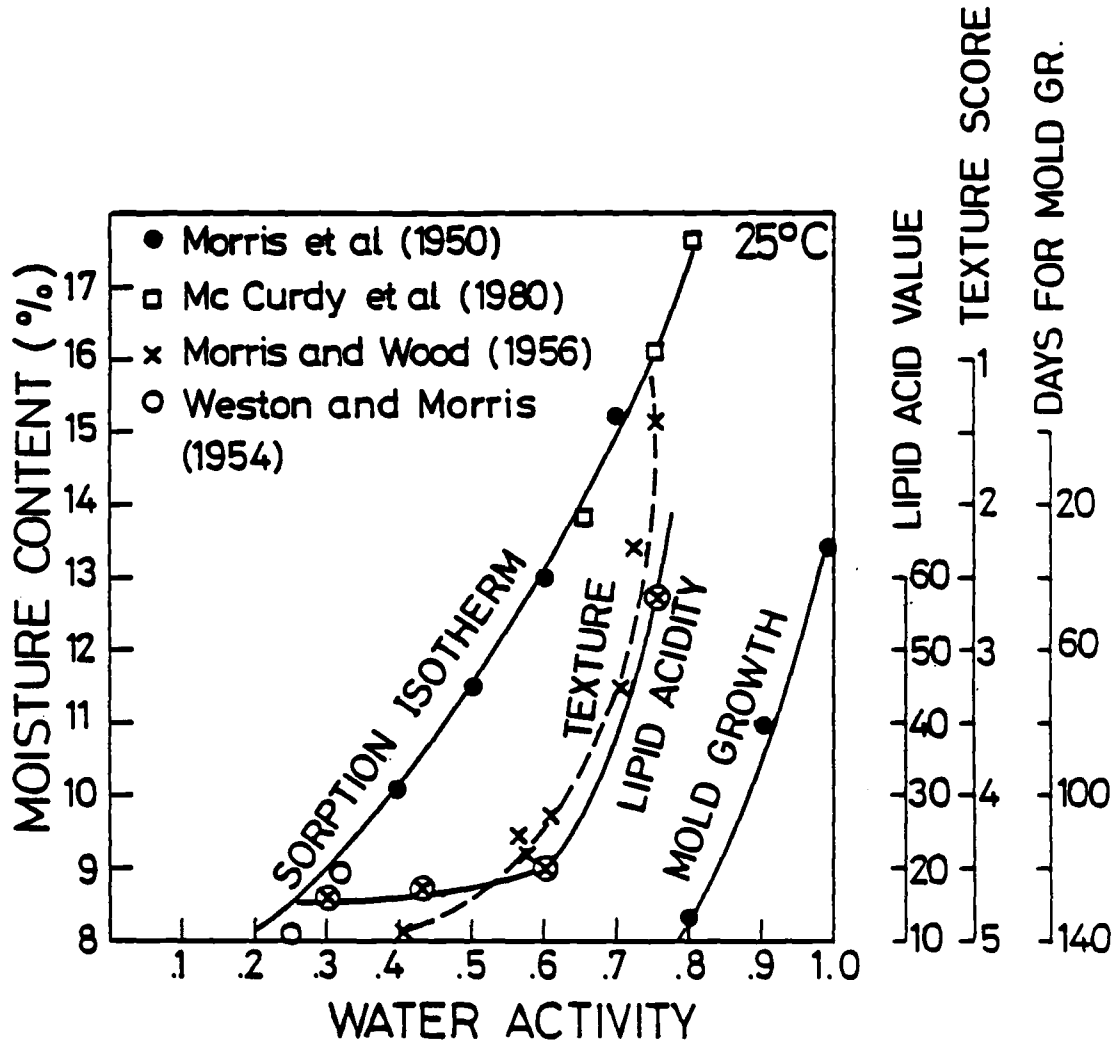

Morris et al (1950)
Mc Curdy et al (1980)
Morris and Wood (1956)
Weston and Morris (1954)
25°C
SORPTION ISOTHERM
TEXTURE
LIPID ACIDITY
MOLD GROWTH
MOISTURE CONTENT (%)
WATER ACTIVITY
LIPID ACID VALUE
TEXTURE SCORE
DAYS FOR MOLD GR.

Figure 3

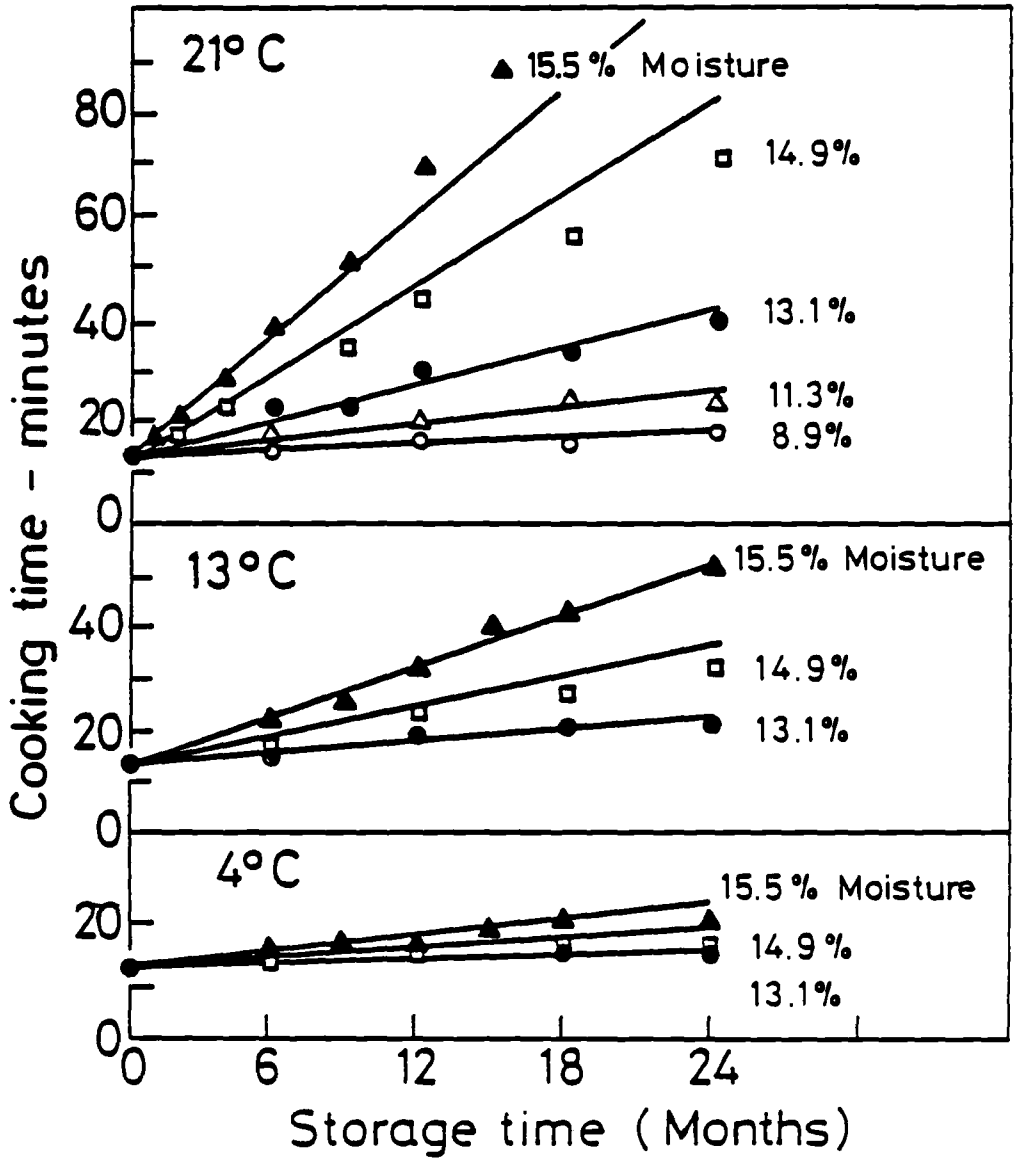
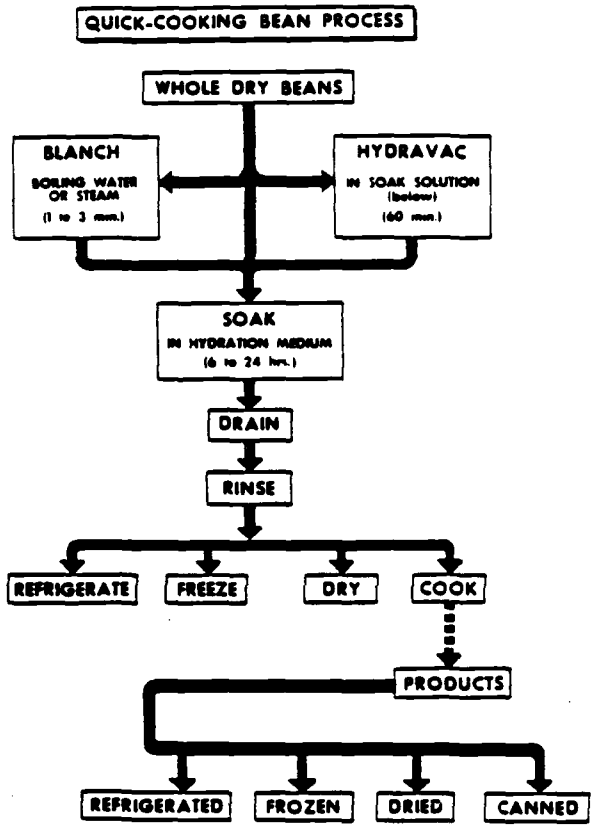
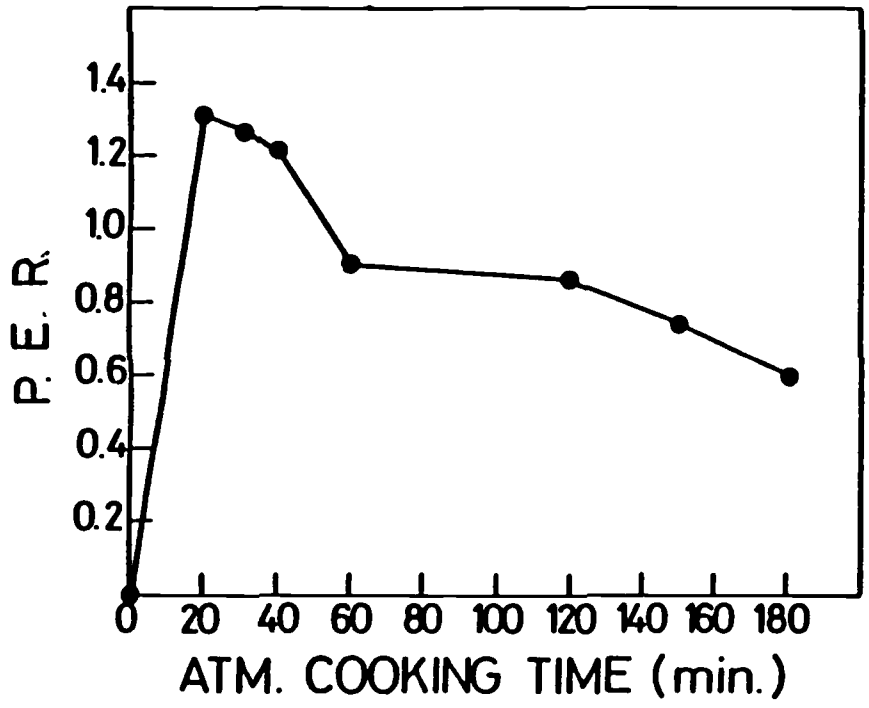

21° C
15.5 % Moisture
14.9%
13.1%
11.3%
8.9%
13° C
15.5% Moisture
14.9%
13.1%
4° C
15.5 % Moisture
14.9 %
13.1%
Cooking time - minutes
Storage time (Months)
0
20
40
60
80
0
6
12
18
24

Figure 4

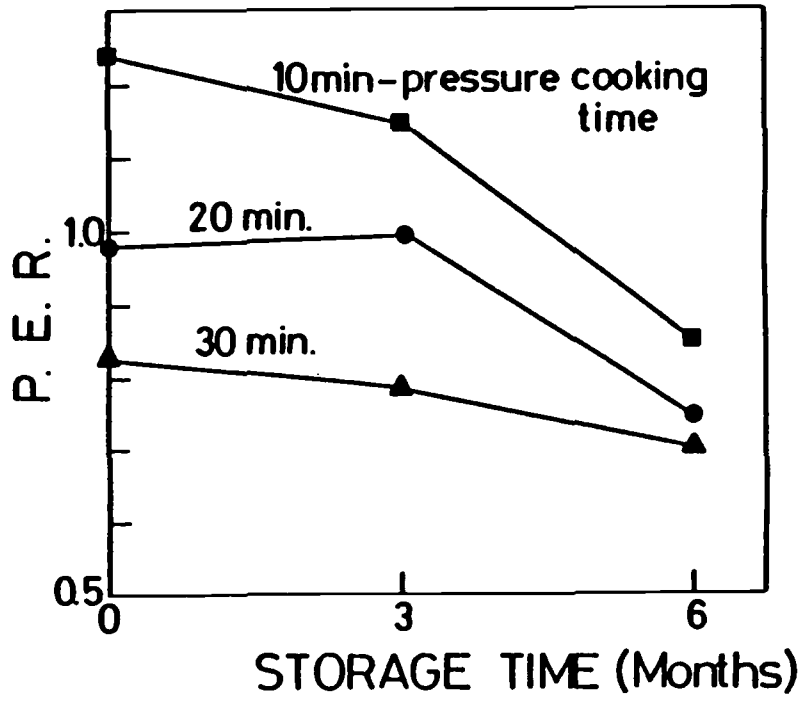


Aguilera and Stanley

Figure 5


P.E.R.
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
20
40
60
80
100
120
140
160
180
ATM. COOKING TIME (min.)

(a)


10min-pressure cooking time
20 min.
30 min.
P.E.R.
1.0
0.5
0
3
6
STORAGE TIME (Months)

(b)

Textural Defects in Cooked Reconstituted Legumes - The Influence of Structure and Composition

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INTRODUCTION

Botanically, legumes are 'dry, dehiscent monocarpellary fruit which open along ventral and dorsal sutures' (Brouk, 1975). But the food scientist realizes that, practically, legumes represent a major source of nutrients for a large part of the human race, including valuable but incompletely balanced protein. It has been estimated (Rockland and Radke, 1981) that the total production of legumes, including dry beans, peas, soybeans, and peanuts, provides almost as much protein to the world as wheat and over 50% more than from either rice or corn (Table 1). As well, legumes supply significant amounts of energy through carbohydrates, fiber, lipid (in the case of leguminous oilseeds), minerals and vitamins including reasonable levels of thiamine, riboflavin and niacin (Bressani and Elias, 1974, 1978). In spite of the nutritional potential of legumes, they are underutilized as food. Many factors limit expanded consumption including those that can be classified as social, nutritional and agronomic (Adams *et al.*, 1977; Giles, 1977), but one of the most important relates to prolonged cooking time and correspondingly higher energy requirements for preparation. This, in turn, reduces the textural quality of the final product, and finally, consumer acceptance. The objective of this review is to examine textural defects in food legumes with special emphasis on structural and compositional factors and to provide a prospectus as to how this problem may be solved. A companion article (Aguilera and Stanley, 1985) is devoted to processing and engineering effects. It should be

pointed out that due to limited space and in order to concentrate on recent developments within this broad field, literature shall be referred to mainly by citing appropriate review articles, from which the reader can trace earlier work.

Classification

Food legumes may be divided into pulses and oilseeds. A pulse is the dried edible seed of a cultivated legume; they are important in human nutrition since they contain a higher percentage of protein than any other natural plant source (Purseglove, 1968). Oilseeds consist of those legumes used primarily for their oil content (Siegel and Fawcett, 1976), although a certain amount of overlap exists between these two groups; for example, soybeans may be consumed directly or used as an oil source. A review of the history of legumes as well as their role in human nutrition may be found in Aykroyd and Doughty (1964) as well as Carpenter (1981) and Heiser (1981).

Definition

Although some legumes are consumed in the immature or fresh state, the majority are harvested as mature seeds containing around 20% moisture, field dried to about 10% moisture and stored under ambient conditions. Final preparation includes soaking in water and cooking the soaked legume in water at atmospheric or elevated pressure. This cooking step, if done for an optimal time, renders the seed nontoxic, improves digestibility, develops acceptable flavor

and also softens the seed coat and cotyledon. The failure of sufficient tenderness to develop during cooking reflects one or more detrimental events occurring at several critical times during the entire spectrum of seed selection, growing, storage and cooking. At the outset, it may prove useful to divide the textural defects of cooked reconstituted legumes into two classes, as determined by the point in the process where they appear:

1) legumes that will not soften sufficiently because of a failure to imbibe a sufficient quantity of water during the soaking step. This defect is commonly termed "hard shell";
2) legumes that will not soften sufficiently because the soaked seeds do not become tender during a reasonable cooking time. This defect is commonly termed "hard-to-cook".

Readers familiar with the literature will acknowledge that considerable confusion has been brought about because of a failure to recognize a delineation between these two events.

Economic importance and distribution

These textural defects are deleterious to commercial value, increase already high fuel costs and yield poor quality products. It is difficult to judge the economic losses resulting from textural deterioration (Coursey, 1983), however, it has been estimated (NAS, 1978) that a total reduction in value of 10 to 50% occurs within the postharvest system in Latin America and that governments have sustained large but unknown economic losses due to these textural

defects (Anon., 1981; de Arevalo, 1982). Some light is shed on this problem through a recent report by INCAP (1983). A number (323) of Guatemalan farmers were interviewed about their production and postharvest handling practices. A summary of the results related to hardening (Table 2) shows that about 10% of the bean crop in this country is lost due to textural defects. It is equally difficult to obtain reliable data regarding the distribution of the problem and the species involved. Guppy (1912) claimed that 85% of 260 legume species examined suffered from some degree of water impermeability. An examination of more recent literature indicate that virtually all food legume species and geographic areas may suffer from this problem.

It is now appreciated that the texture of food products, often their most important quality characteristic, is dictated by the structure of the material which, in turn, is dependent upon an interaction of chemical components and physical forces (Stanley and Tung, 1976). Thus, in order to explain the textural defects occurring in food legumes it will be necessary to begin by studying their structure.

STRUCTURE

Legume seeds may be characterized as generally of medium to large size, more or less compressed and exalbuminous, with a large embryo and a hard, dry, usually smooth testa or seed coat (Corner, 1951). The two major structural parts of legume seeds are the seed coat and the cotyledons or

embryonic leaves but other features include the epicotyl or embryonic stem tip, the hypocotyl or embryonic stem and the radicle or embryonic root; on the surface of the seed may be seen the hilum, which is the scar left where it separated from the stalk and the micropyle, a minute opening in the seed coat (Figure 1).

Seed coat

Legume testae show several major anatomical features (Figure 2). The outermost layer is composed of a thin cuticle which overlies a layer of prismatic, thick-walled contigious cells termed palisade cells. The hardness and impermeability of the dried testa is caused mainly by contraction of the walls of these cells as the seed ripens (Corner, 1951), therefore they are of importance in water absorption characteristics. Hour glass cells are situated between the palisade layer and the stellate mesophyll.

The testa is of obvious concern in determining water absorption but the role of its components is not totally clear. In a study of 13 varieties of pulses, Muller (1967) concluded that the thickness of the palisade layer and the lignin and cellulose content of the seed coat and possible cotyledon cell walls are important determinants of cooking quality. Other workers (Saio, 1976; Hsu *et al.*, 1983) mention such factors as calcium content, seed coat surface, micropyle structure and initial moisture content as being important in water uptake. Structural features responsible for water absorption in cowpeas were studied by Sefa-Dedeh and Stanley (1979b) and it was found that several anatomical

(seed coat thickness, seed volume, hilum size) and compositional (protein content) factors are of importance depending upon the stage of rehydration (Figure 3). Further work on several legume varieties (Sefa-Dedeh and Stanley, 1979c) indicated that seeds with thinner coats absorb water more rapidly during the initial soaking period (0-6 h), after which all the species hydrated at about the same rate.

Cotyledons

The cotyledons form the major part of legume seeds with respect to both weight and volume and exhibit a highly organized structure. Legume cotyledons contain parenchymatous cells bounded by a distinct cell wall and middle lamella (Figure 4) and occasional vascular bundles composed of a large number of closely packed cells. Cotyledon cells differ markedly from typical parenchyma plant cells in that the desiccation occurring during maturation reduces cell organelles (nucleus, mitochondria, SR, etc.) as storage proteins and starch accumulate. These cells contain ellipitcal starch granules embedded in a protein matrix consisting of protein bodies or aleurone grains. The size of these cell inclusions are characteristic of various species. Protein bodies are generally spherical and relatively smaller than starch granules. The protein bodies of legumes are surrounded by a lipoprotein membrane (Sgarbieri and Whitaker, 1982) and contain crystalline inclusions or globoids which are rich in phytin (Lott and Buttrose, 1978, Prattley and Stanley, 1982). Their structure has been reviewed recently

by Pernollet (1978). As opposed to pulses, the cotyledons of leguminous oilseeds such as soybean may be identified by their subcellular structure consisting of protein bodies 5-20 μm in diameter surrounded by a cytoplasmic protein network in which are embedded lipid bodies or spherosomes 0.2 - 0.5 μm in diameter. Further information on the structure of legume seeds may be obtained from Rockland and Jones, 1974; McEwen et al., 1974; Hahn et al., 1977; Silva and Luh, 1978; Rockland, 1978; Sefa-Dedeh and Stanley, 1979a and Wolf and Baker, 1980.

Cell Walls

As will be shown subsequently, cotyledon cell walls are of particular interest from the standpoint of textural defects in legumes. The plant cell wall is that structure surrounding the protoplast and exterior to the plasmalemma, a thin lipoprotein bilayer that functions in transport reactions. In mature cells a secondary cell wall, and, exterior to this, a primary cell wall lie outside the plasma membrane. These structures consist of cellulose microfibrils, hemicellulose and lignin. The primary walls of two cells are joined by the middle lamella. Figure 5 provides a diagram of this organization. Pectic substances constitute a major part of the middle lamella which provides the principal adhesion that holds plant cells together and dictate physical strength of the tissue. There is evidence that this intercellular cement occurs as a polyelectrolyte gel with crosslinking provided by divalent cations in chelate form; the organization of these molecules into fibrils has a

significant influence on texture (Ginzburg, 1961; Sterling, 1975; Dull and Leeper, 1975).

Normal processing (storage, soaking and cooking) produces structural changes in legumes that are related to texture. Cooking induces the largest alteration in structure and, concomitantly, in texture. It is now widely accepted that this occurs due to the separation of cells resulting from thermal degradation of intercellular and cohesive materials (Bourne, 1976; Loh *et al.*, 1982). During cooking, native protopectin forms pectin which depolymerizes rapidly during heating. It follows that compositional differences in pectins could be a major factor determining cookability and this has been shown to account for species differences in thermal behaviour (Loh and Breene, 1982). Heating thus allows cells to separate and softening to occur; cell separation has been reported at 76^{o}C for soaked lima beans (Hahn *et al.*, 1977). Figure 6 shows the influence of heating on the cellular structure of cowpeas. It will be noted that in the uncooked sample fracture occurs across the cell wall but in the cooked material fracture is seen in the middle lamella, leaving cells intact.

Heating and soaking also produces changes in the cell inclusions. Protein bodies do not appear to be disrupted, however, deviations from the normal spherical structures are observed, perhaps due to swelling (Varriano-Marston and Jackson, 1981). Starch granules, on the other hand, demonstrate the deformation, expansion and loss of

birefringence associated with gelatinization, although the presence of intact cell walls impede conformational changes (Hahn et al., 1977). These latter authors recorded the range of intracellular starch gelatinization in soaked beans to be from 76°C to over 95°C. Recent evidence, however, tends to discount a major role for starch in heat-induced softening (Loh et al., 1982).

Textural defects

Textural defects in legumes are accompanied by structural changes, the most noticeable being a failure of cotyledon cells to separate during cooking. This has been observed by Jones and Boulter (1983) using the light microscope. Scanning electron microscopy revealed the presence of intact middle lamella in thermally treated hard-to-cook cowpeas (Figure 7). Varriano-Marston and Jackson (1981) obtained similar results. Sefa-Dedeh et al. (1979) reported no structural changes in uncooked hardened cowpeas that could be observed by scanning electron microscopy but Varriano-Marston and Jackson (1981), using transmission electron microscopy, described disintegration of cytoplasmic organelles and inclusions and loosening of attachments between the cell wall and the plasmalemma of hard-to-cook beans. They considered this loss of plasmalemma integrity to be responsible for increases in electrolyte leakage observed in hard beans as previously reported by Ching and Schoolcraft (1968).

The structural components of legumes have now been described as well as how their organization is related to

textural properties. Next, the compositional factors of legume seeds will be examined.

COMPOSITION

The average proximate composition of several legumes is given in Table 3. The most noticeable feature of these seeds is the high level of protein; a range of approximately 20 to 40% has been reported. This figure, however, can be misleading since it is often derived by using a nitrogen-to-protein conversion factor of 6.25 which, for plant proteins, is high by about 10% and, therefore, overestimates protein content.

Proteins

The storage proteins of legumes have been comprehensively reviewed recently by Mossé and Pernollet (1983) to which the reader should refer for detailed information. Physiologically, the storage proteins of legume seeds, comprising about 80% of the total protein, serve to supply amino acids and a pool of nitrogenous compounds to the young seedling. These proteins are located primarily in protein bodies, the protein content of which is approximately 80%. The remainder of the protein body is composed of phytic acid and mineral elements. The relatively few main storage proteins of legumes, some being glycoproteins, may be characterized by a quaternary structure in which trimers or hexamers are formed noncovalently from subunits of around 60,000 daltons. These structures are capable of the close

packing required for storage molecules. Legume proteins may be classified according to their water and salt solubilities, their heat coagulability, their reaction to changes in ionic strength and pH and the way in which their subunits enter into association-dissociation reactions.

Legume proteins are important because of their contribution to the human diet. Thus, 70 g of beans, the estimated daily intake in Guatemala, provides 4 and 13% of the average adult requirement for energy and protein, respectively (Carpenter, 1981). Although legume seeds exhibit a deficiency in the sulfur-containing amino acids, viz., methionine, cysteine and cystine, they concomitantly supply an excess of lysine, the limiting essential amino acid in cereals (Rockland and Radke, 1981; Sgarbieri and Whitaker, 1982). In evaluating the role of legume proteins in nutrition factors other than quantity and quality must be considered. In order for these amino acids to be fully utilized by humans, a wide variety of potentially toxic antinutritional compounds must be removed or destroyed, usually by heat (Liener, 1978; Nowacki, 1978, Walker, 1982; Sgarbieri and Whitaker, 1982). Even following sufficient cooking to inactivate these factors, protein digestibility of legumes averages only around 77% (Rockland and Radke, 1981), 15-20% lower than casein. This poor digestibility may be related to tannin content of beans (Bressani and Elias, 1978; Elias *et al.*, 1979; Bressani *et al.*, 1982) but does not seem influenced by the starch fraction (Fleming, 1981b).

The effect of hardening on the nutritive value of

legumes has not been extensively studied and, thus, is only poorly understood. Since it is known that longer cooking times are required for hard beans, it may be possible that labile amino acids could be destroyed and protein digestibility be decreased as a result. Also, it is recognized that an optimal cooking time exists for legumes, above and below which digestibility is impaired (Rockland and Radke, 1981). This is an area of research that requires more attention. As will be shown, part of the hardening phenomenon can be attributed to storage times and conditions. Sgarbieri and Whitaker (1982), as a part of their general review on common beans, described the results of several studies on the influence of storage on protein nutritional value. The major common finding is that, as well as increasing cooking time, storage results in decreased PER's, apparently due to both reduced availabilities of both sulfur containing amino acids and lysine and reduced digestibilities. The extent of the nutritional damage produced is determined by the time, temperature and relative humidity of storage.

These nutritional studies and the observation that storage was found to significantly increase nitrogen solubility (Molina et al., 1975, 1976) point to changes occurring in legume proteins during this time. Not a great deal is known about chemical changes in these proteins as a result of storage. Figure 8 depicts previously unpublished data showing the influence of time, temperature and humidity

on ultracentrifuge patterns of water soluble proteins from cowpea. This fraction represents about 70% of the total extractable nitrogen in this species (Sefa-Dedeh and Stanley, 1979d,e). These data, along with gel filtration results not shown, indicate that storage causes a significant reduction in large molecular weight protein fractions and the related formation of smaller fractions. High temperatures and humidities accelerate this effect. It would seem likely that proteolysis is responsible for these changes but it is not known how or if this reaction is related to texture. Ching and Schoolcraft (1968) reported that proteases are active in stored seeds and that their activities are related to moisture and temperature levels. An obvious need is for more detailed information concerning the influence of storage as legume proteins.

Lipids

Another major constituent of legume seeds is lipid and this subject has also been reviewed recently (Pattee *et al.*, 1982 or Salunkhe *et al.*, 1983; these two reviews are essentially identical). Legumes used for human food have total lipid contents, determined as so-called crude lipid or the total quantity of material extractable in organic solvents, varying from about 1 to 50%, pulses occupying the lower end of the spectrum and oilseeds the upper end. Neutral triglycerides represent the major fraction of the compounds present, especially in oilseeds where they are stored as a compact source of energy for the growing seedling. As the total lipid content decreases,

phospholipids, integral components of biological membranes, necessarily increase in percentage. Storage lipids are contained in oil storage bodies termed spherosomes found in cotyledon cells. Nutritionally, oilseeds are an important source of polyunsaturated fatty acids, including essential fatty acids, in the diet. Oleic, linoleic and linolenic are the most commonly found fatty acids with the ratio of saturated to unsaturated acids averaging about 1:3.

Unsaturated lipids have high oxidation potential and the end products of this reaction, such as carbonyl compounds, can chemically interact with, for example, the decomposition products of proteins to yield crosslinked end products. Thus, the storage of legumes can result in a loss of quality (off flavors and odors), nutritional value and functionality. The degree and site of lipid oxidation taking place during storage is variable; Priestley and Leopold (1979), in a paper not referenced in the above reviews, noted that accelerated aging caused small changes in the phospholipid components but did not alter the extent of oxidation of triglycerides.

A study of flavor defects in stored faba beans by Hinchcliffe *et al*. (1977) demonstrated how lipid breakdown may influence quality. Bean flour stored for a year under ambient conditions exhibited 'dry pea flavor' and bitterness as identified by sensory analysis. Since heat treatment sufficient to inactivate lipoxygenase also lowered the intensity of objectionable flavors, it is possible that it is the end products of lipid oxidation that produces these

compounds.

Little is known of the influence of lipids upon hardening, however Takayama et al. (1965) obtained correlation coefficients between triglycerides, phosphatides and crude lipid content versus time. These values did not rise above 0.2 and none were significant. On the other hand, a mechanism had been postulated previously for the involvement of lipids in cooking time of dried beans. Muneta (1964) suggested that the oxidation and polymerization of lipids could produce changes in water permeability which could, in turn, influence texture. It will be noted, of course, that these two publications are not necessarily at odds.

Carbohydrates

The final macro component of legumes to be considered is carbohydrate. Although they are a major constituent of legumes, detailed knowledge of the nature and properties of carbohydrates is limited. Two obvious reasons for this are, first, the broad hetrogeneity of the material, ranging from simple sugars to complex hetropolysaccharides and, secondly, the practice of analyzing for them by difference, viz. deducting the sum of all other constituents (moisture, protein, lipid, fiber and ash) from 100%. This widens the chemical definition of carbohydrate to include other substances such as organic acids and lignin. Some chemical properties of legume carbohydrates have been reviewed recently by Arora (1983).

Legumes (pulses) contain 60-70% total carbohydrate on a

dry basis of which starch is the major fraction accounting for 30 to 40% (Table 4), although a large variety of other carbohydrates are distributed throughout the seed including oligosaccharides, thought to be responsible for flatus, and a range of mono- and polysaccharides. Data in this table were obtained by the sequential carbohydrate fractionation procedure advocated by Southgate (1976) which is becoming accepted as the standard method for such analyses and making previous work questionable. A recent survey of cowpea carbohydrate gave similar results (Longe, 1983).

Starch is found in legumes in the form of oblong starch granules of varying (approximately 20-50 μm) sizes, depending upon species. It has been reported that legume starch granules are resistant to swelling and rupture and are characterized as having an amylose content of about 20-30% (Lineback and Ke, 1975; Naivikul and D'Appolonia, 1979). The influence of cooking on legume starch has been described (Rockland and Jones, 1974; Hahn et al., 1977; Rockland et al., 1977; Silva and Luh, 1978, Owusu-Ansah et al., 1982). Gelatinization temperatures vary from around 60 to over 75°C but these values are known to be strongly influenced by many factors including moisture content, interaction with other components and whether this property is measured intra or extracellularly.

Carbohydrates also play a major role in the composition of cell walls and testae. The chemistry of plant cell walls was reviewed recently by Selvendran (1983) who, along with

Reichert (1981) and Brillouet and Riochet (1983), gives compositional data for the cell wall material of legumes. While the major constituents are pectic substances (ca. 25%), hemicellulose, lignin and cellulose, cell walls also contain about 5-10% of polyphenolic compounds in the form of polysaccharide-protein-polyphenol complexes. The pectic substances comprise an intricate mixture of colloidal polysaccharides formed from pectin (the methyl ester), deesterified pectic acid and its salts (pectates) and certain neutral polysaccarides constituting the galacturonan backbone. The cell wall material was estimated to make up about 7% by weight of the cotyledon.

From the work of Ott and Ball (1943), Powrie et al (1960), Muller (1967), Reichert (1981) and Brillouet and Riochet (1983), it may be deduced that the composition of the seed coat of legume seeds is approximately as follows: water - 8%; and on a dry basis, protein - 5%, polyuronide (pectins) - 20%, cellulose and hemicellulose - 40 to 75%, fat - 0.5 to 1.0%, lignin - 1 to 11%, and ash - 2 to 8%. This is somewhat similar to that mentioned previously for cell walls, but with a higher cellulose content.

The influence of the carbohydrate fraction on legume hardening seems to be centered in three structures, viz. the starch granule, the middle lamella and cell walls, and the seed coat. Aguilera and Steinsaper (1985) noticed that beans having the hard-to-cook defect differed from samples that had been heat processed to retard hardness in that the former exhibited more ungelatinized starch granules. Hahn et al.

(1977) reported variations in susceptibility to gelatinization of starch granules depending upon cellular location while Kon (1979) found starch gelatinization influenced by soaking temperature with higher temperatures (90°C) resulting in slower gelatinization. Jones and Boulter (1983) examined starch isolated from hard-to-cook and normal beans and concluded that the former exhibited a greater swelling power, while Youssef et al. (1982) used the powerful tool of DSC to show differences in thermal properties of starch from hard-to-cook and control faba beans.

A common observation in studies of the influence of cooking on bean structure is that cells from cotyledons with acceptable texture exhibit middle lamellae loosened to the point that individual cells separate without the rupture of cell walls while with hard-to-cook or undercooked beans fracture produces separation across intracellular material. A recent report indicates that failure of middle lamella breakdown may be correlated with increased divalent cation content (Jones and Boulter, 1983). These authors state "pectin solubility (is) much lower in hard beans (produced by elevated storage conditions), coinciding with an increase of 44 and 61% (in) pectin calcium and magnesium.....pectin esterification (also) dropped from 51 to 15% and the quantity of calcium magnesium phytate (decreased) from 29 to 18 mg/g". It should be pointed out, however, that these authors did not reference the work of Kon (1968) who found no significant

difference between either the total pectin substances or its fractions in similar material.

It may be speculated that the observed drop in pectin esterification seen in the hard samples by the former authors might have resulted from the action of endogenous pectin esterase potentiated by the high temperature and humidity conditions of storage. This enzyme cleaves methyl groups leaving a carbonyl moiety to enter into crosslinking reactions in the presence of divalent cations. Figure 9 diagrams how these factors may interact.

Cell walls of red kidney beans were studied by Rozo (1982) who found significant increases in neutral detergent residue, hemicellulose and cell wall nitrogen occurring in beans stored at high temperatures and humidities. These parameters were found to correlate highly with texture hardness. Also, traces of condensed tannins and phenols were found in cotyledons suggesting that Maillard polymeric material was synthesized during storage which may have contributed to the increased hardness. This finding parallels the observation by Molina *et al*. (1976) who described an increase in lignified protein under similar conditions.

Microcomponents

Legume seeds contain many microcomponents in addition to the three major constituents mentioned above and some of these have been implicated in the hardening reaction.

Phytate, myo-inositol hexakisphosphate, is a storage form of phosphorus found in all legume seeds in

concentrations varying from around 0.3 to as high as 2.5% on a dry basis. General reviews of phytate in legumes have been published recently by Cheryan (1980), Reddy *et al*. (1982) and Oberleas (1983). The structure of this molecule provides a strong chelating potential and it binds ionically to divalent and monovalent cations, including certain dietary essential minerals, thus making them biologically unavailable for absorption (Lolas and Markakis, 1975; Kon and Sanshuck, 1981; above reviews). It is becoming increasingly likely that the interaction of phytate and cations is moderated by protein *in situ*. Two lines of evidence point to this conclusion, the first being the cellular location of phytate. In addition to being the site where storage proteins are found, protein bodies also serve as a depository for mineral reserves. In at least some species of legumes, part of the phytate is concentrated in regions of the protein bodies termed globoid crystals (Lott and Buttrose, 1978; Lott *et al*., 1984). Figure 10 shows soybean protein body globoids. Prattley and Stanley (1982) reported that in soybeans most of the phytate occurred in protein bodies, likely in the form of a soluble protein-cation-phytate complex but an estimated 10-15% was present in an insoluble form in globoid crystals. The mechanism of phytate binding provides the second source of information on its form in the natural state. Prattley *et al*. (1982) demonstrated through binding experiments that at physiological pH soluble protein-calcium-phytate complexes were produced and that calcium was required for the

association of protein with phytate, leading to the conclusion that salt linkages are formed among these three constituents.

Since phytic acid would seem to be present in legume seeds mainly in a water soluble form, it is probable that the aqueous processing steps associated with legume preparation, i.e., soaking and cooking, would result in significant removal of this compound. This has been demonstrated numerous times from the landmark work of Mattson (1946) onward to the studies by Chang *et al*. (1977, 1979) and Kon (1979). These studies indicate that phytate is readily removed from whole legume seeds. The mechanism for this reaction is twofold: diffusion into the surrounding medium and enzymatic hydrolysis. The proportion attributable to each reaction is dependent upon time, temperature and medium interactions but, as an example, Chang *et al*., 1977 found that white beans soaked at 60°C for 10 h lost almost all their phytate with about 75% being hydrolyzed and 25% diffusing into the soak water. Kon (1979) showed a significant conversion of organic to inorganic phosphorus even at 20°C for 16 h.

The enzyme responsible for catalyzing the *in vivo* hydrolysis of phytate is phytase, a phosphohydrolase (E.C. 3.1.3.8.) that produces inositol and phosphoric acid in a 1:6 molar ratio. It has been demonstrated to be present in many legumes and to be particularly active in germinating seeds (Eskin and Wiebe, 1983). In the extracted form this enzyme has been characterized as having an optimum pH of 5.2 - 5.3 and an optimum temperature of 50-60°C (Chang and Schwimmer,

1977; Lolas and Markakis, 1977) although Becker *et al.* (1974) claim the optimal temperature for the formation of inositol in ground white beans is 35°C, indicating a possible role for cellular structure in mediating this reaction. In the same vein, it is of interest to note the observation by Chang *et al.* (1977) that *in vivo* phytate hydrolysis is dependent upon access of enzyme to substrate; a 20% increase in reaction rate occurred when beans had been previously frozen and the mechanism suggested was the destruction of membranes induced by ice crystal formation. This enzyme has also been implicated in reduced germination of stored seeds (Ching and Schoolcraft, 1968).

The importance of phosphate compounds in bean hardening has been emphasized in the literature from 1903 onwards (Mattson, 1946). This author convincingly demonstrated that hard-to-cook peas contained much less (over 50%) phytate than normal and that removal of this compound by soaking or enzymatic action induced this textural defect. The mechanism for this compound in normal tissue was postulated to involve a chelation of divalent cations from the middle lamella by phytate, thus eliminating pectate crosslinking and aiding in its dissolution during cooking. Hard-to-cook tissue fails to soften due to a lack of phytate. Similar observations have been recorded over the ensuing years up to the recent report by Jones and Boulter (1983) that black beans in which the hard-to-cook phenomenon had been brought about by storage at elevated temperature and humidity contained about 35% less

phytate than a control sample. An example of such a study is the work of Kon and Sanshuck (1981) who similarly effected increased cooking time in white beans. Their data indicate that reduction in phytate content was the best predictor of increased hardness. Soaking hard beans in solutions of either phytate or the chelating agent EDTA prior to heating reduced cooking times to that of the control beans. When this species was supplemented by eight other legumes, it was found that a significant negative correlation coefficient of -0.71 existed between cooking time and the ratio of phytic acid to calcium in the cotyledons.

Other workers have not always obtained similar results. For example, Crean and Haisman (1963) expressed the view that since the available phytate can only, at maximum, complex less than 50% of the divalent cations during cooking, free calcium and magnesium ions are always available to crosslink middle lamella pectins and, hence, the influence of phytate on texture is small. Rosenbaum and Baker (1969) studied cooking times relative to phytate content and calcium diffusion and noted that a more rapid rate of cooking, associated with the interior of the cotyledon, is not a function of phytate content but rather it is diffusion of water through the seed coat into the cells and the ease of hydration and solubility that determine cookability. Variations in phytate, divalent cations and total phosphorus in both pinto and lima beans were found not to explain differences in cooking times for these species.

It is possible that the differences in response to

phytate observed above may be explained by the presence of another microcomponent of legume seeds. Polyphenols in cereals and legumes have been receiving a great deal of recent attention due to their adverse influence of color, flavor and nutritional quality. The compounds of interest are the tannins and flavanoids. This subject was reviewed recently by Salunkhe *et al.* (1982) and also served as the subject of a symposium (Hulse, 1980). Tannins are the polyphenols that seem to be of most importance in legumes. These are defined as normal metabolic products consisting of water soluble phenolic compounds having molecular weights between 500 and 3,000 daltons and possessing the ability to precipitate alkaloids and gelatin and other proteins (Gupta and Haslam, 1980). Perhaps the two most commonly occurring monomeric molecules in this classification are both isomeric flavan-3-ols, catechin and epicatechin, which can condense to form hexameric and heptameric polymers with molecular weights of 1700-2000 daltons. Bresseni and Elias (1980) showed that these polyphenols differ in quantity in common beans with respect to seed coat color. White, red and black varieties contained 0.34 - 0.42, 0.57 - 1.15 and 0.95 - 1.29% polyphenols, expressed as tannin acid, occurring mainly in the seed coat. It should be noted that the method of analysis chosen significantly influences the results obtained (Bressani *et al.*, 1983).

Polyphenols decrease protein digestibility in animals and humans, presumably by either making it partially

unavailable or by inhibiting digestive enzymes even though significant losses of these compounds occur to the cooking water since the broth is often consumed (Bressani and Elias, 1980). There is also some evidence that trypsin inhibitor activity may, in fact, be a product of heat - labile 'true' trypsin inhibitor and a heat stable factor composed of polyphenols (Fernandez et al., 1982).

Not much seems to be known about the polyphenolases of legume seeds. Zenin and Park (1978) reported velvet bean contains a high (about 5%) level of L-DOPA, an endogenous substrate for polyphenolase in faba beans (Schwimmer, 1981). In what may be a related observation, Rolston (1978) reviewed literature that suggested that the impermeability of legume seed coats is assocated with higher levels of phenolic compounds in the seed coat and with their level of oxidation involving polyphenolases. The browning or tanning reaction, found to be correlated with impermeability, is considered to be a consequence of quinone formation via the action of catechol oxidase on the diphenols resulting from polyphenolase activity. The compounds thus produced can interact with each other and with proteins.

It seems possible that the enzymatic oxidation of polyphenols is also involved in the hard-to-cook phenomenon. Workers at INCAP (INCAP, 1983) stored black and red common beans at various temperatures and humidities for up to 6 months in order to induce hardness. Samples were analyzed for catechin and polyphenolase activity and these data were then correlated to hardness parameters. It was found that

decreases in catechin content and increases in polyphenolase were favored by the more severe storage conditions that also led to harder beans. A role for polyphenols in bean hardening through an enzymatic mechanism involving polyphenolase was postulated. More information on this subject would be welcome.

A final microcomponent, also thought to be capable of influencing bean texture, is lignin. This is a network-type polymer composed of substituted alcohols. The three-dimensional structure consists of short linear chains crosslinked by a variety of interchain covalent bonds. It is uncharged, insoluble and widely distributed in plant tissues where it exists covalently bound to the hemicellulose components of the cell walls and middle lamella (Blouin *et al.*, 1982). The function of lignin is to decrease the permeation of water across cell walls, impart rigidity and bond cells, thus creating a structure resistant to impact, compression and bending (Sarkanen and Ludwig, 1971). Lignification, or the *in vivo* formation of lignin, proceeds by oxidation and polymerization of polyphenols. Proteins can interact with the phenolic precursors of lignin in two ways (Blouin *et al.*, 1982); reversibly by hydrogen bonding and irreversibly by oxidation and condensation reactions. These proteins are glycoproteins, contain hydroxyproline and attach to polysaccharides of cell walls (Preston, 1979). Phenol oxidation may occur enzymatically (via polyphenol oxidase) or nonenzymatically (Blouin *et al.*, 1982). Whitmore (1978)

reported that a polymer of coniferyl alcohol, a polyphenol, became bound to various hydroxyproline-containing proteins in a reaction catalyzed by peroxidase and inferred that this reaction may be "the earliest step in crosslinking of the primary wall and before massive lignification and secondary cell wall formation begin". Siegel (1956) also suggested a role for peroxidase in lignification as did Ranadive and Haard (1972). The enzymatic control of lignification has been reviewed by Hahlbrock and Grisebach (1979). It is worth mentioning that peroxidase is both heat stable and prone to regeneration (Schwimmer, 1981).

With respect to cooking of legumes, the importance of these reactions of lignin is not fully known, however, Loh et al. (1982) suggested that the presence of protein in the cell wall and middle lamella may lead to stronger cohesion after heating as a result of denaturation. Muller (1967) gathered data impinging on the lignification reaction in legumes. Following an examination of the cooking quality of 13 varieties of peas and beans with and without seed coats, it was concluded that while a combination of phytin, Ca^{++}, Mg^{++} and free pectin values could reasonably predict hardness in the majority of species, two purple-flowering types exhibited a greater hardness than expected. As well as failing to soften readily upon cooking, they were less susceptible to citrate tenderizing, whose action was attributed to divalent cation chelating ability. Chemically, the purple-flowering peas exhibited a much higher lignin content and it was concluded that it is this constituent of

the middle lamella, not removeable by chelators, which was responsible for the anomalous results. It is of particular interest to note that in this study two brown bean varieties were tested and it was found that although they also contained high amounts of lignin, they were softened by citrate. The telling factor here, however, may be the observation that the brown specimens had a much thinner palisade layer and much lower cellulose content in the seed coat, implying higher permeability.

Another line of evidence implicating lignin in bean hardening comes from the work of Molina et al. (1976) who employed heat as a process to reduce textural defects in stored black beans. When samples were treated by retorting or by heating under atmospheric steam, it was found that hardness was retarded during 9 months of storage at 25°C/70% RH. As well, the heat treatments exerted a beneficial influence on water absorption capacity of the beans but this was not correlated to hardness. It is of importance that although these moist heat treatments succeeded in reducing hardness relative to an unheated control, all the treatments hardened during storage when compared to a sample kept at 4°C. The more severe the heating, the more hardening occurred. Another most interesting finding in this study was that elevated storage conditions produced a noticeable increase in lignified protein that paralleled closely (R =

0.91) the development of hardening. Heat treatment slightly reduced lignification in the cotyledons but not in the seed coat, however, none of these values were close to the much lower results obtained for samples stored at 4°C. It should also be noted that the intensity of cotyledon color decreased as lignified protein increased, implicating polyphenols in this reaction. Thus, in highly colored beans, if enzymatic reactions, presumably phytase, are eliminated by heat, a delay in hardening will be seen but lignification still takes places and is highly correlated with the degree of this defect finally attained.

Subsequently, Aguilera and Steinsaper (1985) placed recently harvested Chilian black beans in an externally heated metal drum for 3 min by which time an internal temperature of 105°C had been reached in the seeds. Following 10 months storage at 22°C, cooked heated beans were statistically significant but mathematically slightly more tender than an unheated control (397 g for the control versus 345 for HTST, as measured by the puncture test).

More significantly, even though the heat treatment significantly reduced the development of hardness relative to an unheated control, 10 months storage produced a quite large degree of hardness in beans that had been so severely heat treated that only 2.5% would germinate. These data, if it is assumed that the samples contained no active enzymes, argue strongly for a nonenzymatic component to bean hardening. If the experiments of Molina et al. (1976) are recalled, the

process of nonenzymatic lignification may explain these results. It will be noted that both groups worked on highly colored black beans that contain elevated levels of polyphenols.

Now that the structural and compositional factors involved in hardening have been examined, it is of importance to consider how legume texture may be measured.

TEXTURE MEASUREMENT

In order to quantitate textural defects in legume seeds, some way must be found to measure hardness and softness. Four types of approaches have been used for this purpose; mechanical, physical, chemical and sensory, but textural measurements based on mechanical properties have been the most common.

Mechanical Properties

Of all legumes, fresh peas have been the most thoroughly investigated in regards to texture since this quality factor determines both harvest time and financial return. The pea tenderometer is the most widely used and best established instrument to determine pea tenderness. It was introduced in 1937 and became the first commonly employed texture instrument. The tenderometer consists of a grid of blades rotated at constant speed through a second grid; as the peas are cut by the blades, the maximum force is indicated by a pointer moving over a graduated scale (Voisey and deMan, 1976). This procedure has been used for cooked dried beans

but the data did not agree with determinations of cook time (Muneta, 1964).

To explain the methods developed to measure the texture of legumes one must, again, start with the work of Sante Mattson (Mattson, 1946; Mattson *et al.*, 1950). This researcher realized the importance of obtaining values for individual beans in order to construct a continuous cooking curve and minimize the effect of biological variation when looking at multibean samples. Accordingly, an ingenious device was constructed that required no moving parts or power source (Figure 11). The basis of this apparatus is a number of individual plungers which are placed on the top of single beans contained in a cook pot that provides steam. As cooking progresses, a point occurs where the weighted plunger penetrates the testa and cotyledon allowing the tube surrounding the plunger to drop 3-4 cm. This is recorded and a curve is obtained that shows beans cooked as a function of time (Figure 12). This apparatus has since been used with modifications by several workers (Morris and Seifert, 1961; Morris, 1963; Burr *et al.*, 1968; Jackson and Varriano-Marston, 1981) and has been adapted for automatic recording (Burr, 1976).

Individual cooked reconstituted beans can also be evaluated by means of a penetrometer in which a probe is forced into the sample and the required force is measured. This approach was used by Bourne (1972), Molina *et al.* (1976) and Aguilera and Steinsaper (1985) although the probe size differed (3.2 mm vs 2.2 mm vs 3.0 mm). Advantages of this

approach include its partially nondestructive nature so the samples can be obtained for microscopy from tissue of known textural response and the histograms that can be constructed from the data (Figure 13).

Texture measurements based on multibean samples have also been developed. A multiblade shear press was developed similar to the pea tenderometer except that a linear instead of a rotary motion is used. It was soon used to test fresh peas (Kramer and Aamlid, 1953) and later for cooked legume seeds (Salunkhe and Pollard, 1955). Binder and Rockland (1964) used this apparatus to estimate the cooking rates of lima beans and this approach has continued to receive much use in evaluating bean texture. Other test cells used to measure the texture of multibean samples include a cylindrical cell (Lee, 1970), extrusion cells (Voisey and Larmond, 1971), wire extrusion cells (Voisey and Nonnecke, 1972) and a compression cell (Anzaldua-Morales and Brennan, 1982).

The previous methodologies all deal with cooked beans. As mentioned previously, hardening defects can occur at different processing stages and by different mechanisms so that it becomes important to be able to measure the texture of raw and soaked legumes as well. To this end, an apparatus was constructed to evaluate these samples that uses a wedge-type blade mounted to an Instron testing machine to cut across these harder cotyledons (Sefa-Dedeh et al., 1978). This device is shown in Figure 14 and allows data to be

gathered for experiments such as those studying the effect of soaking on texture.

Physical Properties

Several physical tests have been used with legumes to obtain data thought to correlate with texture. Bourne (1967) reported that although density could not be used, beans with poor texture are removable by size grading. Cooking time has proven to be a useful measure of texture and is often reported as the time required for 50% of the sample to cook. This latter parameter may be evaluated by squeezing between the forefinger and thumb (Jones and Boulter, 1983), by recording the time when 50% of the beans are split (Hulse *et al.*, 1977), by sensory panel or by any of the instrumental methods mentioned above. Chemical tests, *per se*, have not been widely employed for predicting texture, perhaps due to the time required for their completion.

Water absorption seems to correlate well with cooked bean texture although it depends if rates or total amounts are compared; the rate of water absorption does not appear related to texture (Burr *et al.*, 1968; Sefa-Dedeh *et al.*, 1978, 1979; Quenzer *et al.*, 1978; Jackson and Varriano-Marston, 1981) but all these authors found that intact beans stored at high humidities absorbed more water or at a faster rate than either fresh beans or beans stored at low humidities. Cooking time within a treatment is, however, strongly dependent upon total moisture content. Both Sefa-Dedeh *et al.*, (1978, 1979) and Jackson and Varriano-Marston (1981) have demonstrated this dependence.

Sensory Properties

Sensory tests are often used to either correlate with instrumental methods or in their place. Such tests are reported by Morris and Wood (1956), Voisey and Larmond (1971), Kumar *et al.* (1978), Silva *et al.* (1981), Anzaldua-Morales and Brennan (1982), Jones and Boulter (1983) and many others. Most frequently, they involve evaluation of 'doneness' in the mouth, which can vary since consumer preferences differ markedly depending upon region, socio-economic background, etc. In developing countries, preferences for basic foodstuffs like dry beans are often sharply defined. Correlations between sensory and instrumental data are frequently not given but Shehata *et al.* (1983) found significant ($P \leq .01$) relationships between softness scores and both penetrometer readings and maximum Kramer shear forces while Silva *et al.* (1981) reported a correlation coefficient of 0.77 between puncture force and sensory texture for black beans cooked at 100°C and 0.87 for samples prepared at 121°C. Aguilera and Steinsaper (1985) found a correlation coefficient of 0.93 between sensory evaluation and puncture force for the same species.

Another form of textural evaluation is the routine screening of quality characteristics performed by legume breeders who realize that, besides yield and nutritional value, the acceptability characteristics of new varieties are of paramount importance for their successful introduction. In order to evaluate consumer acceptability, CIAT, in Cali,

Colombia, the international agricultural organization charged with legume breeding, gathers data on water absorption, cooking time, broth quality and tendency to harden during storage (CIAT, 1983). Another regimen has been suggested for legume breeders by Hulse et al. (1977) that includes the parameters of size, hydration coefficient, cooking time, seed hardness and broth thickness.

MECHANISMS

For as long as textural defects in reconstituted legumes have been known, and they were reported as early as the Third Century B.C. (Morris and Seifert, 1961; Bourne, 1967), attempts have been made to uncover an explanation for this behaviour. This section of the review will endeavour to explore the many possible causes that have been advanced. In order to characterize these mechanisms, the classification scheme introduced earlier will be used.

Hard shell defect

This defect, the failure of seeds to imbibe sufficient amounts of water prior to cooking, has been shown, both in amount and rate, to be inheritable but only partially influenced by agronomic conditions (Rolston, 1978). It appears that storage conditions are not an important factor in this defect which is primarily physical in nature. The author of the above review concludes that the structural element responsible for hard shell is the testa but more specifically the palisade layer contained within the seed coat, the hilum, the strophiose, and various waterproofing

substances. These latter materials are formed enzymatically from oxidized monophenols which can produce pigmented polyphenol complexes that may interact with proteins. It may be possible that this reaction is important because it leads to lignification as discussed previously. Thus, although something has been learned of this defect, it would certainly be an exaggeration to claim that the mechanism for hard shell is completely known.

Hard-to-cook defect

In the hard-to-cook defect seeds imbibe water but do not soften sufficiently during cooking. This deficiency seems of more practical importance to the consumers of legumes than hardshell, especially in countries where high temperatures and humidities are encountered. Based on the available evidence, the mechanism differs significantly from hardshell, being primarily chemical rather than physical in nature. Agronomic factors such as fertilizer levels and composition can play a major role and storage conditions are also important.

Although a number of hypotheses have been developed over the past century to explain the hard-to-cook defect, there can be no doubt that the one advanced most frequently is essentially the same as Mattson's 1946 theory, although this, in part, was based on prior observations. It holds that insoluble pectates, located in the middle lamella, are rendered dissoluble upon cooking by replacement of their divalent with monovalent cations. This depends upon a

biological chelator to sequester the Ca^{++} and Mg^{++} ions and a pool of monovalent cations, Na^{+} and K^{+}, to replace them. The agent most often evoked is phytate which presumably diffuses to the middle lamella.

Legume seeds stored at high temperatures and humidities for extended periods develop the hard-to-cook defect. An explanation for this is that phytase hydrolyzes its substrate and the reaction products are no longer capable of chelation. Recent findings that these storage conditions also produce altered, presumably more permeable, membranes (Varriano-Marston and Jackson, 1981) and the evidence for proteolysis mentioned previously can be used to explain solute leakage and the physical joining of phytate and phytase.

This middle lamella-cation-phytate-phytase theory has been used to explain the bulk of the data gathered on the hard-to-cook defect but, as mentioned previously, not all researchers agree with it. Also, of course, even all these studies taken together do not prove conclusively its absolute correctness and, as pointed out by Varriano-Marston and Jackson (1981), a cause-and-effect relationship between phytate hydrolysis and decreased cookability of legumes has not been unequivocally demonstrated. What does seem undeniable is that the mechanism producing the hard-to-cook defect in stored legumes is at least partially enzymatic. This is evidenced not only by the conditions that produce the defect but also the treatments that are effective in preventing it (Elias, 1982). It would seem much too early to discount a contributing role by several other processes, any

of which, given a certain set of conditions, could assert itself. The former author lists a group of possible alternate mechanisms, some of which have been cited previously in this review. They include phenolic-protein complexes (presumably because this reaction is a precursor to lignification); starch swelling, gelatinization and retrogradation; and lipid oxidation and polymerization.

Many of the possible mechanisms for legume hardening are enzymatic in nature. These possibilities, some obviously speculative, are listed in Table 5. The previous discussion of lignification and its apparent ability to process in heated material introduces the possibility of a nonenzymatic component of hardening as well. In summary, it may be said that while much information has been gathered on textural defects in legumes, the complex mechanisms responsible are not fully known and, more importantly, the relative significance of each one under varying conditions has not been investigated systematically.

PROSPECTUS

If the reader has persevered to this point, it will be obvious that the subject of this presentation exists in a state of scientific uncertainty. In this concluding section, an attempt will be made to provide a summary of the information at hand and an inventory of what is required.

It would seem safe to conclude that:

1) The hardening of legumes during storage under adverse

conditions is a universal phenomenon that inflicts real losses and an associated decline in economic return for farmers in geographic areas where high ambient temperature and humidities are found. The associated reduced utilization of legumes and increased preparation time and fuel requirements are both nutritionally and economically costly for the people of these areas.

2) The mechanisms producing this defect are several and incompletely dominant. Scientific thought has favored an early hypothesis that ascribes prolonged cooking times in stored legumes to a failure of phytate to chelate divalent cations in the pectates of the middle lamella, rendering this structure unsusceptible to heat softening. The phytate in this case is not able to fulfill its role due to the action of phytase, presumably activated by elevated storage conditions.

However, it has now been shown by two independent researchers that in highly colored beans, hardening will proceed at a quite respectable rate even if a severe heat treatment has been employed. This evidence requires acceptance of a nonenzymatic pathway if one can discount enzyme regeneration, de novo protein synthesis and the explanation that the endogenous enzyme may have been sufficiently thermally potentiated prior to inactivation to convert significant amounts of substrate. One possible nonenzymatic mechanism is a type of case hardening, i.e., proteins and/or starch become unable to absorb water following harsh heating. Another

possibility is suggested by the finding that lignified protein is built up in the cotyledons of heat treated colored beans during storage. Can this reaction proceed nonenzymatically? As noted in a previous section, it is not possible to verify this presently but at least one step seems able to and one of the enzymes involved (peroxidase) is resistant to heat.

Thus, the picture emerges of three major factors influencing hardness of cooked legumes, each incompletely dominant. Phytate and the associated effect of chelators seem of greatest importance in most varieties but highly colored species show elevated levels of polyphenols, more lignin and only a limited reaction to chelators. This may be overcome, however, by thinner/less tough cell walls. Obviously, other mechanisms may also be important if conditions for their reactions are optimized.

3) Although the contribution of each of these mechanisms is not known, and probably varies from situation to situation, empirical knowledge has allowed the partial inhibition of hardness during storage by various methods such as heat but in no case are the results totally satisfactory. Clearly, advances in this area await further elucidation of the causes of hardening. For example, if lignification proves a significant factor, it remains to be discerned how the process can be controlled technologically.

4) In light of these conclusions, a scientific course of action, consisting of questions that should be addressed, becomes clear:

   A) Why do heat treated beans harden during adverse storage conditions (but not if kept at 4°C)? Does this imply a nonenzymatic hardening process, or simply enzyme regeneration, enzyme persistance, or case hardening?

   B) If there is a nonenzymatic hardening process, does it occur via lignification?

   C) Can a practical method be developed to control these reactions at the production level in developing countries?

   D) Can plant breeders and genetic engineers solve this problem?

The economic and nutritional importance of textural defects in cooked reconstituted legumes to producers, processors and consumers underscores the need for continuing intensive research into this problem.

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FIGURE LEGENDS

Fig. 1. Structure of typical legume seed. Left - external view; Right - internal view. Source: Northen, 1958.

Fig. 2. Structure of cowpea testa. CS - cotyledon surface; SCS - seed coat surface; CU - cuticle; PAL - palisade; SR - subhilar region; HGL - hour-glass cells; MES - mesophyll. Source: Sefa-Dedeh and Stanley, 1979a.

Fig. 3. Generalized water absorption curve for cowpea showing components accounting for majority of variation. Source: Sefa-Dedeh and Stanley, 1979b.

Fig. 4. Cross section of cowpea cotyledon. ML - middle lamella; PB - protein body; S - starch granule. Source: Sefa-Dedeh and Stanley, 1979a.

Fig. 5. Diagram of a plant cell wall. Source: Bourne, 1983.

Fig. 6. Structure of cowpea as influenced by heat. A - heated to 100°C; B - heated 90 min at 100°C. Source: Sefa-Dedeh, 1978.

Fig. 7. Cowpea stored for 12 mo and heated at 100°C for 45 (A-C) or 90 (D-F) min. A,D - stored at 0°C, 80% RH; B,E - stored at 21°C, 35% RH; C,F - stored at 29°C, 85% RH. CW - cell wall; ML - middle lamella; MLR middle lamella remnants. Source: Sefa-Dedeh et al., 1979a.

Fig. 8. Ultracentrifuge patterns of cowpea water soluble proteins. A - stored at 29°C, 85% RH for 7 mo; B - stored at 0°C, 80% RH for 7 mo; C - stored at 29°C, 85% RH, 12 mo; D - stored at 0°C, 80% RH, 12 mo; E - stored at 21°C, 35% RH, 12 mo; F - stored at 21°C, 35% RH, 7 mo. Source: Sefa-Dedeh, 1978.

Fig. 9. Schematic plan of relationship among legume components and texture. Arrows - Ca^{++} flux; H - hardness; S - softness; PE - pectin esterase. Source: Schwimmer, 1981.

Fig. 10. Soybean protein body globoids. A,B - cross section of protein bodies showing globoid inclusions (g) and cavities (c) arising from dislodged globoids. C,D - isolated globoids. Source: Prattley and Stanley, 1982.

Fig. 11. Diagram of bean cooker rack and plungers. Source: Jackson and Varriano-Marston, 1981.

Fig. 12. Cooking curve output from bean cooker showing percent cooked as a function of cooking time. Data are for influence of fertilizer additives. Source: Mattson, 1946.

Fig. 13. Histograms of puncture force for individual cooked black beans. Source: Aguilera and Steinsaper, 1985.

Fig. 14. Dimensions of wedge (A) and plate (B) test cell. Source: Sefa-Dedeh *et al.*, 1978.

Table 1. World production of protein and lysine by major food legumes and cereals in 1975 (10^3 MT).

	Protein	Lysine
Soybeans	25,800	1,805
Dry beans	11,500	805
Peanuts	2,500	105
Legumes, total	39,800	2,715
Wheat	42,600	815
Corn	25,800	775
Rice	24,000	935
Cereals, total	92,400	2,525

Source: Rockland and Radke (1981).

Table 2. Production characteristics of Guatemalan beans related to textural defects. Data from 323 farmer interviews.

Species (% of total crop)	%		
P. vulgaris	93		
Other	7		
Attributed reason for hardening (% of total response)			
Sun exposure	21		
Prolonged storage	17		
Months of storage required for hardening	5.9		
Bean losses (% of total crop)			
Postharvest handling (physical and drying losses)		14	
Storage and marketing		18	
Humidity			4.4
Insect attack			3.6
Seed hardening			9.9
Total loss		32	

Source: INCAP (1983).

Table 3. Proximate composition of several dry legumes (%).

Species	Water	Protein	Fat	Total CHO	Ash
Kidney bean (Phaseolus vulgaris)	10.4	22.5	1.5	61.9	3.7
Lentil (Lens esculenta)	11.1	24.7	1.1	60.1	3.0
Cowpea (Vigna unguiculata)	10.5	22.8	1.5	61.7	3.5
Pigeon pea (Cajanus cajan)	10.8	20.4	1.4	63.7	3.7
Groundnut (Arachio hypoguea)	5.4	26.3	48.4	17.6	2.3
Soybean (Glycine max)	10.0	34.1	17.7	33.5	4.7

Source: Aykroyd and Doughty (1964). Modified.

Table 4. Carbohydrates in 7 whole legume seeds (% DB).

		$\bar{x}$	Sd
Fiber	- crude	4.26	1.58
	- acid	6.92	1.74
	- neutral	9.26	1.66
Sugars	- Total sol. in 80% MeOH	8.48	1.96
	- raffinose	.65	.43
	- stachyose	2.93	1.12
	- verbascose	1.24	.96
Polysaccharides	- starch	34.8	6.09
	- glucans	.55	.13
	- pentosans	1.55	.50
	- cellulose	3.23	.99
	- hemicellulose	.62	.25
	- lignin	4.31	4.30

Source: Fleming (1981a).

Table 5. Possible enzymatic mechanisms for bean hardening.

Enzyme or reaction	Action	Consequence
Phytase	Hydrolyzes phytate to inositol and orthophosphate	Loss of ability to chelate divalent cations
Pectin esterase	Removes methyl groups of pectin, exposes carboxyl groups	Crossbridging of pectin carboxyl groups by divalent cations
Lipoxygenase	Conversion of lipids to polar, oxygenated polymers	Degradation of membranes, solute leakage, increased enzyme-substrate interaction
Proteases	Hydrolysis of storage proteins	Production of lower m.w., more reactive proteins capable of interacting
Peroxidase *et al.*	Crosslinking of polyphenols to proteins of cell walls	Lignification

CANADIAN/CHILEAN PROJECT
How to build a better bean

by Gerald Toomey and Dennis Lewycky

For centuries, dried beans have been a major source of protein and essential amino acids in the human diet. Whether they end up on as baked beans on a dinner table in Guelph, Ontario, or as porotos, a thick bean soup, in Santiago, Chile, they are seen by millions of people around the world as a nutritious, tasty and inexpensive food that keeps well.

While all dried beans take much longer to cook than fresh beans, some suffer from a poorly understood biochemical phenomenon known simply as the "hard-to-cook" defect or textural hardness. It is a major hurdle to the full acceptance and use of dried beans and other legumes by consumers, especially in developing countries.

Because of the commercial potential and nutritional value of beans, a group of Canadian and Latin American scientists have teamed up in a co-operative research network to investigate the hardness problem. The research involves two projects each of which has two components.

One such project is a three-year venture involving food scientists at the University of Guelph and chemical engineers at the Catholic University of Chile (PUCC). The Guelph group is investigating the biochemical mechanisms that cause beans to harden during storage. The Chileans are concentrating on the thermal properties of beans in order to develop simple and inexpensive roasting techniques that will arrest hardening, allow beans to be stored longer, and reduce cooking times. In each case, the object of study is *Phaseolus vulgaris*—the common bean.

According to one of the project leaders, Dr. David Stanley of Guelph's Department of Food Science, "the total production of legumes, including dry beans, peas, soybeans and peanuts, is estimated to provide almost as much protein to the world as wheat and over 50 percent more than either rice or corn." Global annual production of grain legumes is currently over 50 million tonnes, of which common beans account for about 20 percent.

For the consumer, excessively hard beans waste cooking fuel because they can take from two to three hours to cook—twice as long as regular beans. To make matters worse, hard-to-cook beans are also hard to digest and the extra cooking reduces their protein value.

The hard-to-cook defect shouldn't be confused with "hard shell". The latter phenomenon refers to the inability of some dried beans to imbibe water through the testa, or seed coat, during soaking. The hard-to-cook defect, on the other hand, arises in the cotyledon—the interior portion of the bean containing the embryonic leaves. Hard-to-cook beans do in fact absorb water when soaked, but don't soften sufficiently during cooking.

The commercial implications of the hard-to-cook defect are, of course, neg-

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ative. Hard beans either fetch a much lower price or can't be sold at all. In Central America, for example, farmers lose up to 35 percent of their crops through post harvest losses, and excessive hardening is a significant part of this.

Hardness has already been correlated with adverse storage conditions—namely high temperature and humidity—often found in tropical countries. At Guelph, then, an initial component of the research program has been a one-year storage study, begun in mid-1984, to induce the hard-to-cook defect under controlled conditions. This is providing Stanley's team with the raw material needed to carry out biochemical and microstructural studies required to elucidate the actual hardening mechanisms.

Chilean black beans were divided into two groups: beans that were field-dried in the traditional manner, and those that were field-dried and then heat-treated (roasted) by the Chilean researchers in a sand-filled drum for two minutes at 150C. Some of the regular field-dried beans are being stored at high temperature (35C) and high humidity (85 percent), others at low temperature (15C) and, low humidity (35 percent). The heat-treated beans were divided into the same two storage groups. The regular and heat-treated bean samples stored at low temperatures and humidities serve as controls.

A number of tests were performed on the bean samples at intervals during the storage study. One set of tests determined textural hardness of bean samples in the raw, soaked and cooked states. The forces in kilograms required to cut through the seed coats and cotyledons of raw and soaked beans were measured with an Instron Universal Testing Machine. For the cooked beans, the measurements were made with an Ottawa Texture Measurement System (OTMS).

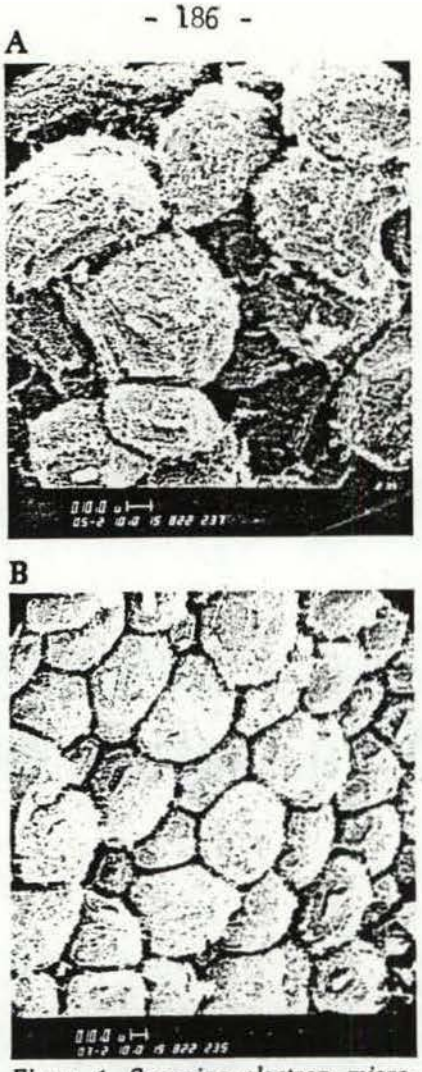


Figure 1. Scanning electron micrographs of cooked beans: (a) low-temperature, low-humidity storage. (b) high-temperature, high humidity storage.

For the raw bean test, it was found that beans stored at high temperature and humidity exhibited a dramatic increase in hardness in the first month of storage, with the texture remaining constant thereafter. The low-temperature, low-humidity control beans retained their tenderness throughout the storage period.

For the cooked bean texture test, the trend was a gradual toughening of those beans stored at high temperature and humidity. Again, the control beans retained their tenderness. In the case of soaked beans, the samples exhibited similar textures no matter what the storage conditions or treatment method, indicating that hard shell had not occurred.

A second set of tests on the bean samples focused on enzyme activity. It has long been known that hard-to-cook legumes contain less phytate (a storage form of phosphorus in the cotyledon) than normal beans. Another micro-component, the enzyme phytase, which is particularly active in germinating seeds, promotes the degradation of phytate.

Crude phytase extracts from bean powder were assayed for enzyme activity by measuring inorganic phosphorus levels in the reaction mixture. Phytate was isolated from the samples by means of column chromatography. Dr. Stanley's group found that, as expected, the bean samples stored at high temperature and humidity exhibited higher phytase activity and smaller amounts of phytate than the control samples.

The Guelph scientists also carried out microstructural studies on the bean samples using transmission and scanning EM and light microscopy. Preliminary data on regular dried beans support the textural data. According to Michael Hincks, the Canadian PhD candidate working on this problem at Guelph, the hard-to-cook phenomenon in regular dried beans stored at high temperature and humidity "is evident microstructurally as restricted cell separation and greater integrity of the cell wall/middle lamella complex". (See Figures 1 and 2.)

The middle lamella is the intercellular cement that binds the exterior walls of individual cotyledon cells together, thus dictating the physical strength of the tissue. Pectic substances constitute the major part of the middle lamella. When normal beans are cooked, this cohesive material degrades, allowing the cells to separate. In hard-to-cook beans the cell walls and middle lamellae retain their strength so that separation of cotyledon cells is minimal.

Further research will examine the biochemical mechanisms underlying these processes.

One important hypothesis under study concerns the role of phytase and

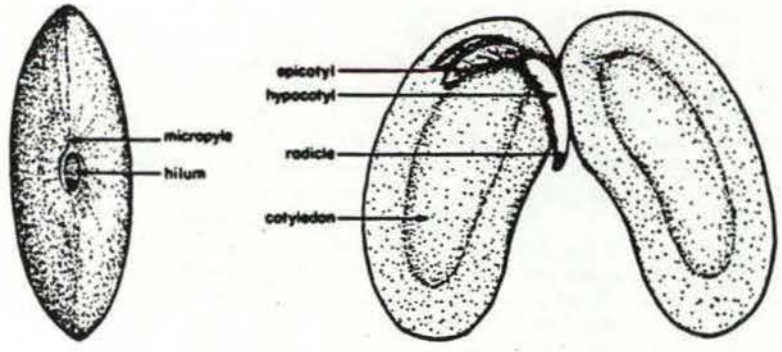


Figure 2. Diagram of bean seed. Left, external view. Right, seed with seed coat removed. Source: "Introductory Plant Science, Second Edition," by H.T. Northen, The Ronald Press Company, New York, 1958, p. 35.

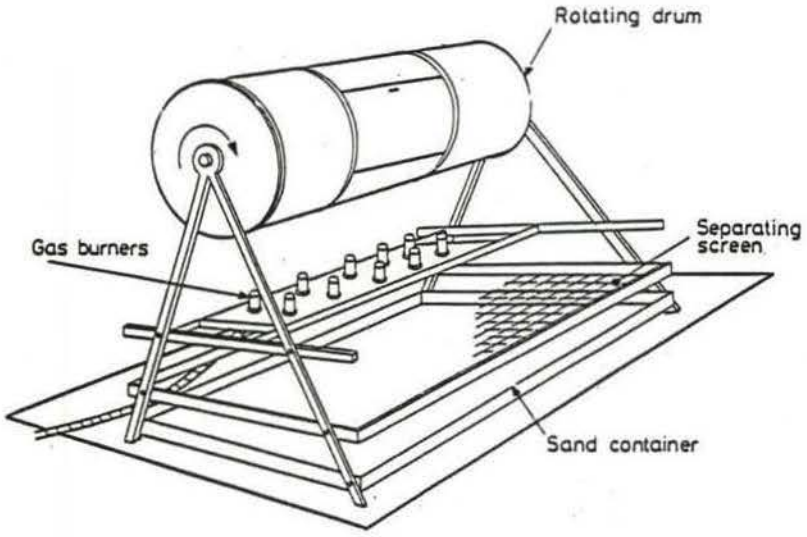


Figure 3. Inexpensive experimental roaster developed at Catholic University of Chile.

phytate in the middle lamella. The structure of the phytate molecule gives it a strong chelating potential, that is, the ability to bind ions. It is thought that phytate chelates divalent metal cations (e.g., calcium and magnesium) from the middle lamellae of normal beans. This would eliminate pectin crosslinking and aid in the breakdown of the middle lamella during cooking. In hard-to-cook beans, the hypothesis goes, the reduced level of phytate due to phytase enzyme activity inhibits chelation and, consequently, softening.

While phytase does appear significant in bean hardening, there is little concrete understanding of how it is involved and what other chemical reactions stimulate hardening. For example, two other possibilities are lignification (hardening into a woodlike substance) and the capacity of starch to gelatinize (soften and expand).

Post-harvest technology

The PUCC portion of the research focuses on the development of economically feasible post-harvest techniques to arrest bean hardening. In particular, the Chileans are investigating the principle of high-temperature, short-time particle-to-particle heat transfer. The same heat treatment used on some of the bean samples sent to Guelph has been the focus of this work.

According to Dr. J.M. Aguilera of PUCC, there seem to be two main effects of the heat treatment. "First, it decreases their initial and final hardness, probably by enzyme denaturation, partial starch gelatinization or other effects. Secondly, it dries the beans so that they can be stored at lower moisture contents, in which case the hardening rates are slower."

An important tool in this thermal research is a simple rotating drum roaster in which beans are mixed with sand to ensure an even distribution of heat. (See Figure 4.) The PUCC scientists are thus able to study heat transfer coefficients, temperature profiles inside the beans, energy expenditure, and physical effects on the seed coat. Part of their work will be to define roasting parameters such as rotation speed, sand temperature, and sand-to-beans ratio, with a view to adapting the roaster for small-scale use in villages.

Another part of the Chilean research will be to monitor the effects of moisture content and storage temperatures on the rate of hardening of both untreated and heat-processed beans.

This work will lead to field tests of the inexpensive roaster with producers and consumers, and a look at alternative bean-preparation and storage technologies appropriate to local economic and social conditions.

The Guelph-PUCC research project is one of two aimed at improving the quality and consumption of beans. Meshing with it is a second project on which the Department of Foods and Nutrition at the University of Manitoba is collaborating with the Nutrition Institute of Central America and Panama (INCAP) in Guatemala City. Researchers at the two institutions are surveying consumer preferences, identifying sensory qualities that influence preference, and quantifying physical, chemical and sensory characteristics of common beans. Standard evaluation procedures developed by the researchers will be used to compare the effects of storage practices and processing treatments on bean quality, and for comparison with other bean products.

Canadian funding

Both projects, scheduled to be completed in mid-1986, are financially supported by the Ottawa-based International Development Research Centre (IDRC). Created by the Canadian parliament in 1970, IDRC assists developing countries in solving their socio-economic and development problems through scientific research in a number of disciplines. The Centre has funded research on legume quality in several other countries including Egypt (faba beans), Lebanon (lentils) and Guatemala (common beans).

Andrew McNaughton and Bill Edwardson program officers in IDRC's Agriculture, Food and Nutrition Sciences Division, say that past work has attempted to establish correlations between mineral, protein or starch content, seed components, and the degree of hardness after various stages of storage. "But what is also required, and what the Guelph-PUCC project will provide," says Edwardson, "is a basic understanding of bean-hardening mechanisms. In the process, researchers on the two projects are also laying the groundwork for future investigations by standardizing bean samples for handling, cooking procedures, and hardness tests for both physical instruments and human senses."

What makes this research stand out from most projects of this nature is their collaborative methodology. To help the work go smoothly and ensure that the research has a practical impact, a network of the four participating institutions was created.

IDRC was in a good position to know of different but compatible research possibilities on dried beans, says McNaughton. So when an initiative for the hardening research came from PUCC and Guelph, the other institutions were drawn into a network "to address the problem as a whole and in the most efficient way".

"Such a multi-faceted problem cannot be solved by one institution alone," says Stanley. Therefore, co-ordinating research and increasing interaction between researchers leads to "more tangible returns for the each organization's investment".

While new information on bean hardening is the central objective of the projects and the network, the participants will gain in other ways as well. The Latin American institutions have gained access to Canadian expertise and are getting working experience with advanced technologies. The Canadian universities gain by being able to work and exchange information within new environments. More importantly they see their research play a role in solving an increasingly difficult human problem—feeding the world. □

ABSTRACT

NAVY BEAN COOKABILITY EVALUATION
BY
MODIFIED MATTSON BEAN COOKER
AND BY
SENSORY PANELS

JAMES ROY PROCTOR

Mattson bean cooker procedures described in the literature were modified to reproduce the sensory evaluation of the cooking time of navy beans. Neither the plunger types nor the 50% cooked point comparison method described in the literature measured cooking time in a manner consistent with sensory evaluation. Plungers modified to 48 g in weight and to a 5 mm flat-faced penetrating end provided cookability curves that corresponded with cookability curves provided by a 9 member trained sensory panel. Preference testing by the 9 member panel indicated that the preferred cooked percentage was 93.7% SD 8.68%. Therefore it was decided that the 92% cooked point provided a better comparison point than the usual 50% cooked point. Averaging the time required to attain the 92% cooked point for four replications of 25 beans each, provided a method of comparing the cooking times of bean samples that reflected the within-sample variability.

When cookabilities of Seafarer, Fleetwood and Exrico navy beans grown at Brandon, Morden and Winnipeg were compared, effect of growing location

was greater than the effect of cultivar. Cooking times for all three cultivars were significantly longer ($P<0.05$) when grown at the Winnipeg location. Exrico beans grown at Winnipeg location took significantly longer to cook ($P<0.05$) than Fleetwood or Seafarer, but at other locations cultivars had similar cooking times. Post-harvest drying was not found to affect cooking time of the Seafarer-Winnipeg samples. Cooking times of the artificially dried and field dried samples were not found to be significantly different ($P<0.05$). There was no incidence of hardshell in any of the freshly harvested navy bean samples. There was no evident relationship found between moisture content, fat, protein, ash or phytic acid and cooking time.

The cookabilities of Seafarer and Fleetwood cultivars grown at Winnipeg, Brandon and Morden locations and stored for 9 months under freezer, prairie outdoor ambient (POA) and simulated semi-tropical (SST) conditions were measured at three month intervals. The Fleetwood samples had much longer cooking times (a minimum of 40 minutes longer) after freezer storage while the Seafarer samples were not significantly affected. The Fleetwood samples showed a high incidence of

hardshell (12% to 32%) while the Seafarer had 0% hardshell under freezer storage. Under POA storage conditions, the Fleetwood samples had 16% to 20% hardshell and prolonged cooking time under frozen outdoor (February-3 month) conditions but were unaffected at 6 and 9 months (May, August). Seafarer samples were unaffected by POA storage conditions. Under SST conditions, Fleetwood samples were unaffected, while the Seafarer showed a slight rise in cooking times of 12 to 15 minutes over the 9 month period. Neither cultivar showed any incidence of hardshell under SST conditions. The samples grown at the Winnipeg location had consistently longer cooking times than the samples grown at the other locations.

Samples of Fleetwood navy beans grown at three locations were stored under freezer conditions for a period of nine months. The cookabilities of the hardshell and non-hardshell fractions in blanched and unblanched samples were assessed and compared. Blanching reduced incidence of hardshell from as high as 32% to 0%, and reduced the cooking time of the hardshell fraction in all three samples. The cooking time of the non-hardshell fraction was prolonged between 5 to 25 minutes.

LEGUME TEXTURE EVALUATION

INSTRUCTIONS:

1) % COOKED:
Evaluate 20 beans at random from each sample and record on ballot the numbers that you consider, according to your judgement, to be "undercooked" or "cooked".

Note: The "cooked" category should include all beans that are just barely cooked to overcooked. It does not indicate only the perfectly cooked beans.

Note: Choose at random from all of the beans in the sample. Do not choose only the whole beans. Include the partial beans and beans with split skins.

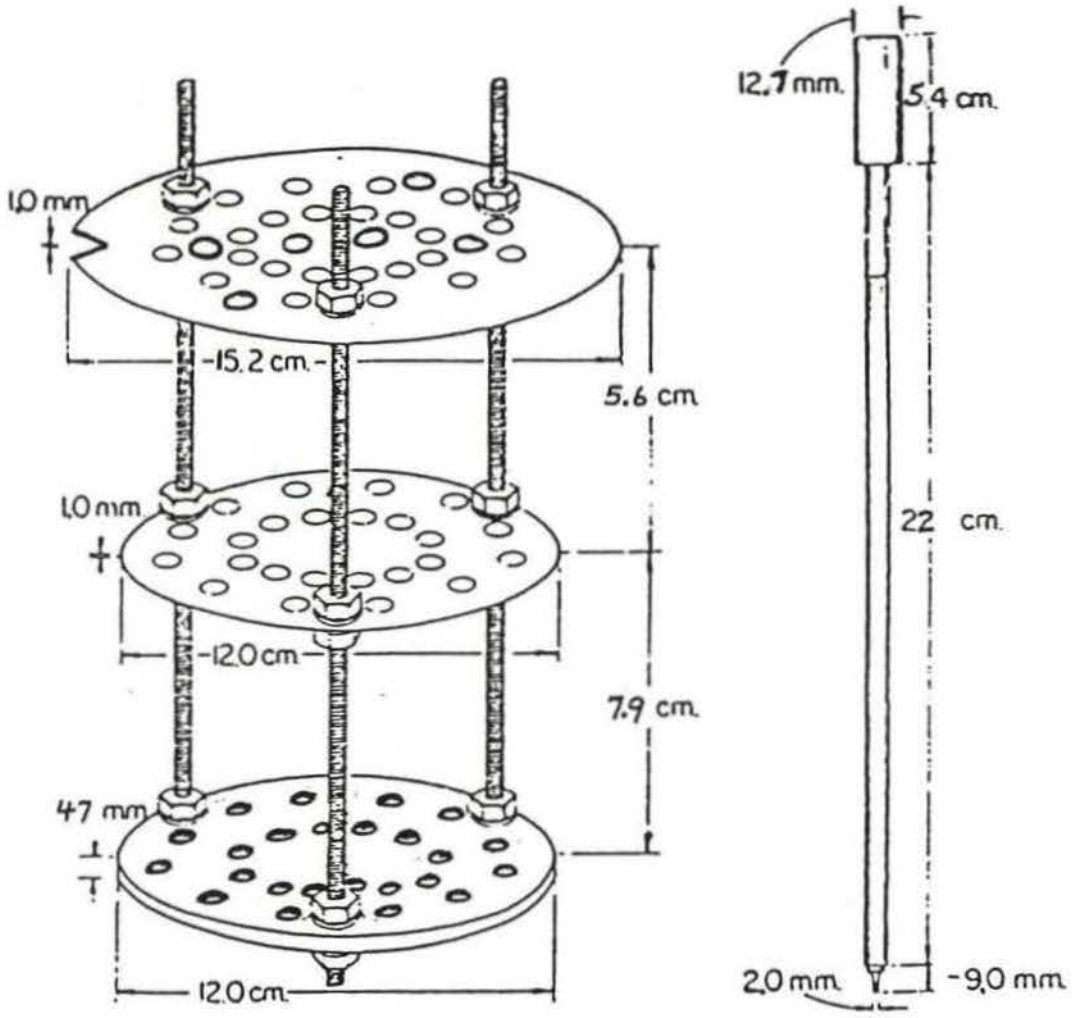
2) PREFERENCE:
From each sample select a spoonful (approx. 10 beans) and chew all at once. Evaluate for overall texture preference. Circle the sample number of the sample that you preferred.

SAMPLE BALLOT

SAMPLE	NUMBER OF BEANS UNDERCOOKED	NUMBER OF BEANS COOKED

Figure 3-4. Sample of ballot used by nine member sensory panel.[1]

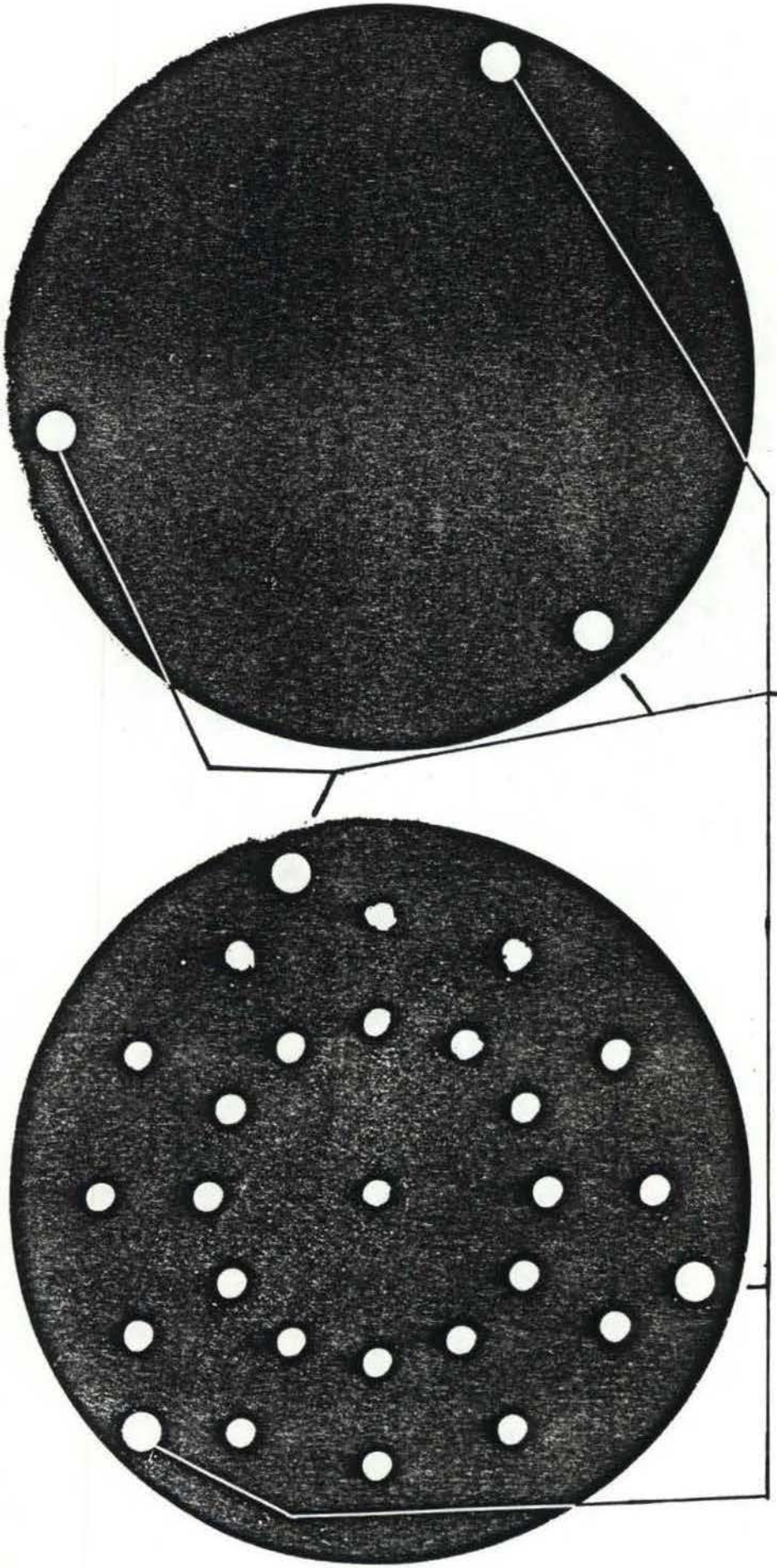
[1]The same ballot, but without the Preference section was used by the five member sensory panel.



Dimensions of rack and plungers of Mattson Bean Cooker (Dept. of Foods and Nutrition)

TYPES OF PLUNGERS USED WITH MATTSON COOKER

Dept. of Foods and and Nutrition
U. of Manitoba
September 1985



BOTTOM PLATE

1.14 cm thick

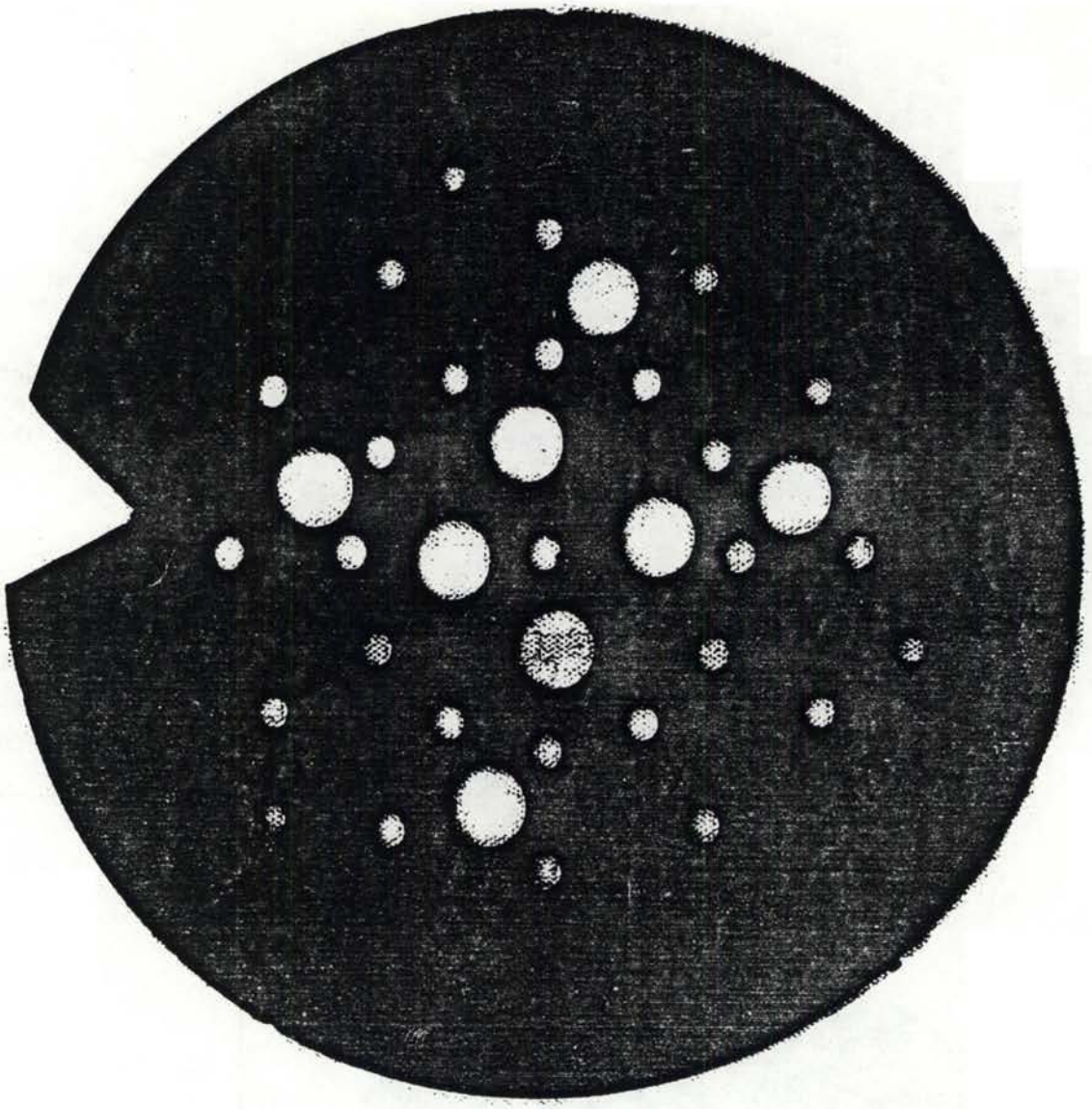
The holes correspond exactly to those in the middle plate, but are only 0.4 cm in diameter.

Threaded connecting rods (3) go through these holes

MIDDLE PLATE

0.1 cm thick
(i.e. 1 mm)

Holes are 0.5 cm in diameter



TOP PLATE

0.1 cm thick

holes are 0.5 cm in diameter

This plate is bigger that the other two so that it will rest on top of a pyrex pot and suspend the rest of the cooker. Also, it has some additional large holes to let steam escape.

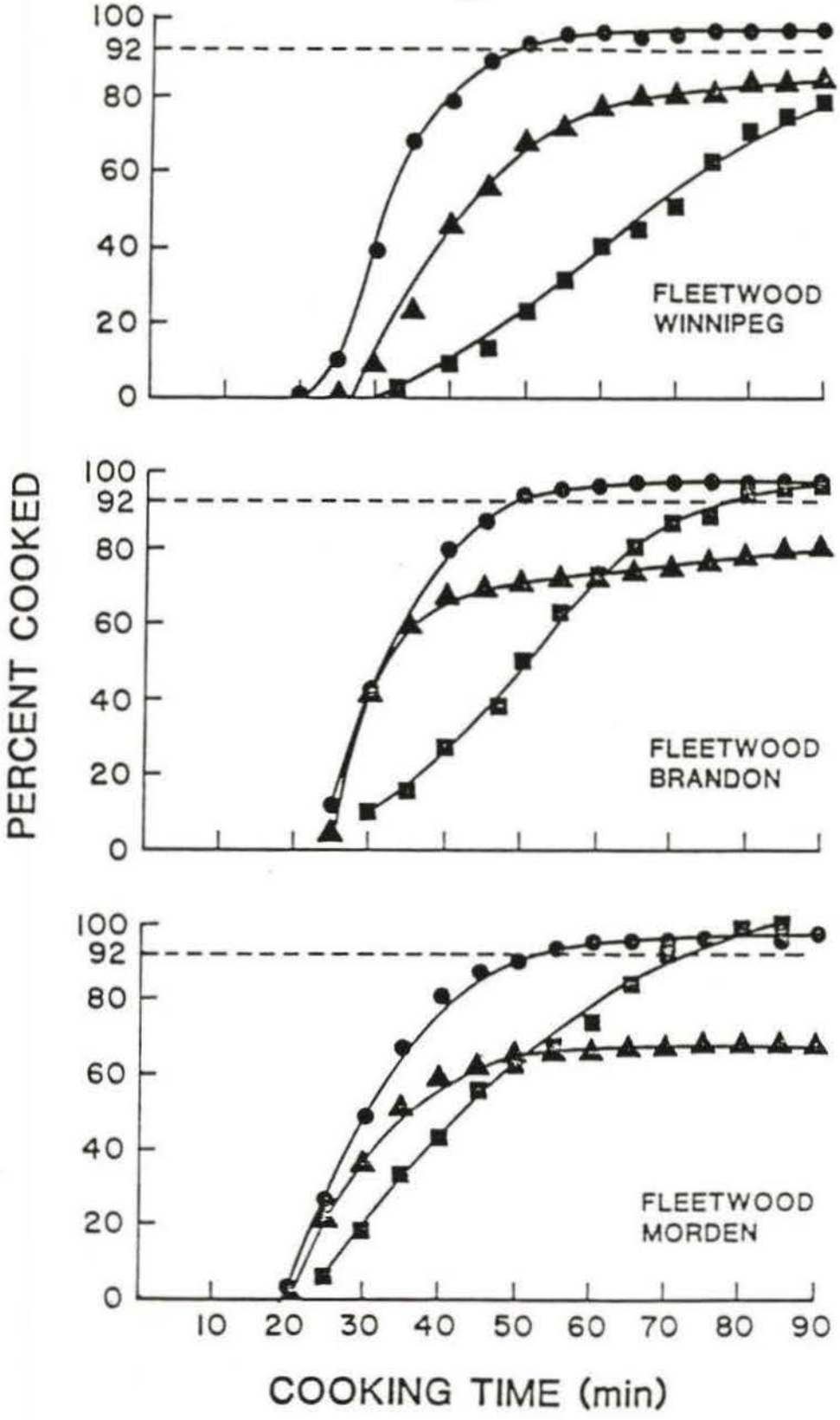


Figure 6-1. Cookability curves for blanched and unblanched Fleetwood navy bean samples grown at three locations.

● - 0 month
■ - blanched-9 month-freezer
▲ - unblanced-9 month-freezer

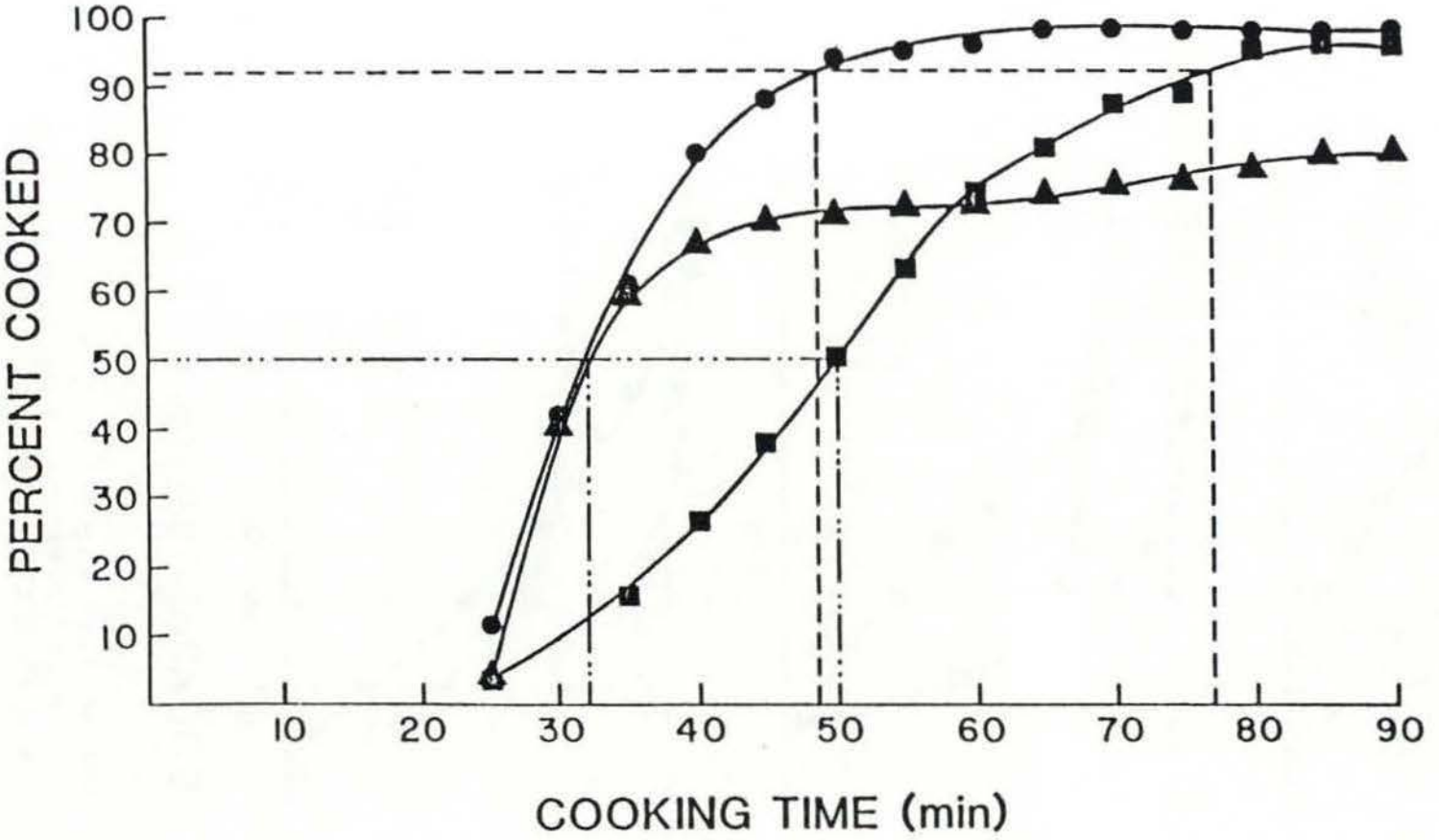


Figure 3-8. Cookability curves for three samples of Fleetwood navy beans as determined by the MBC with comparison of cooking time required required to reach 50% cooked point and 92% cooked point.

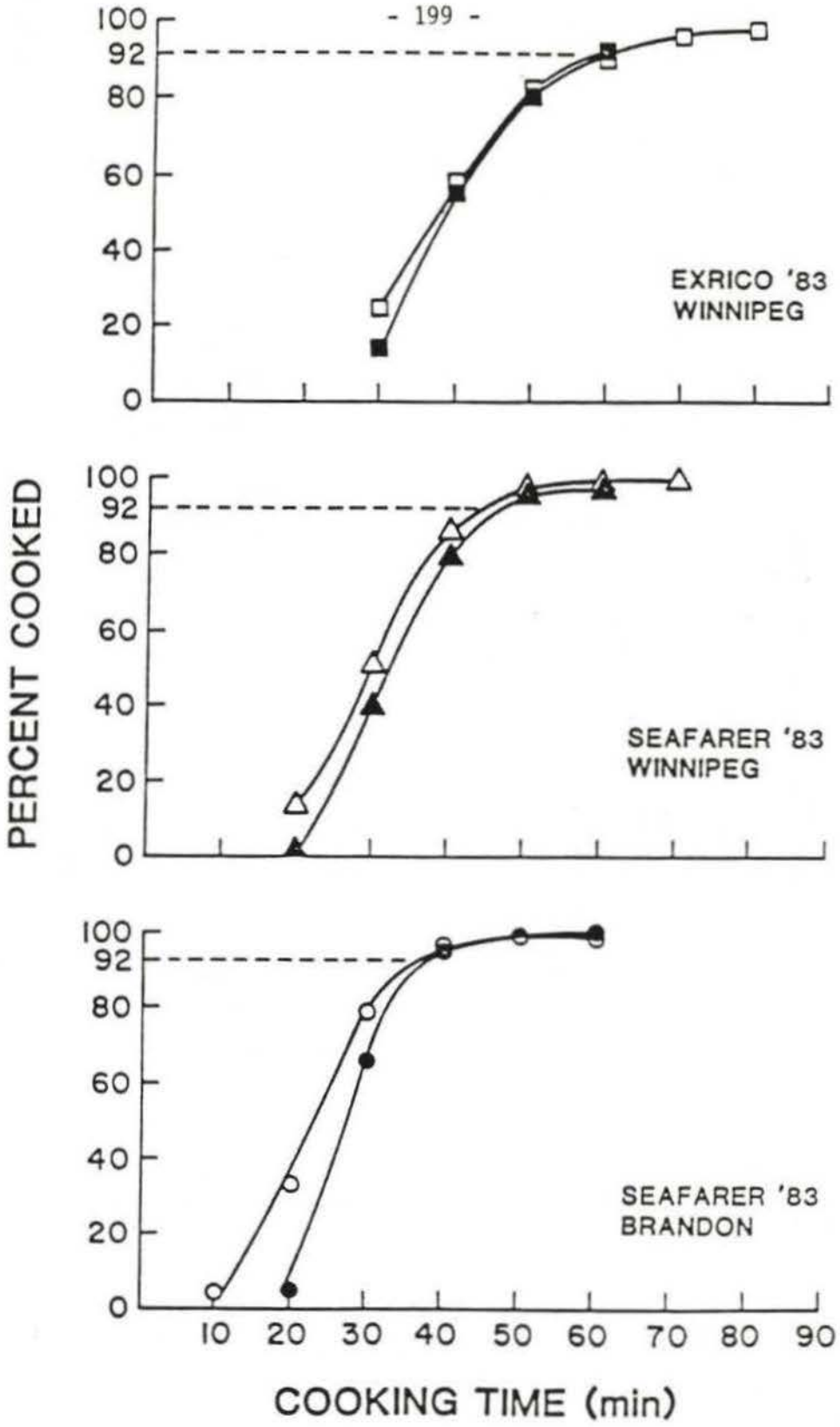


Figure 3-7. Cookability curves for 3 samples of navy beans as determined by the MBC with 48 g, 5 mm plungers and by a 9 member sensory panel.

● - MBC - Seafarer-1983-Brandon
○ - Panel - Seafarer 1983-Brandon
▲ - MBC -Seafarer-1983-Wpg
△ - Panel - Seafarer-1983-Wpg
■ - MBC - Exrico-1983-Wpg
□ - Panel - Exrico-1983-Wpg

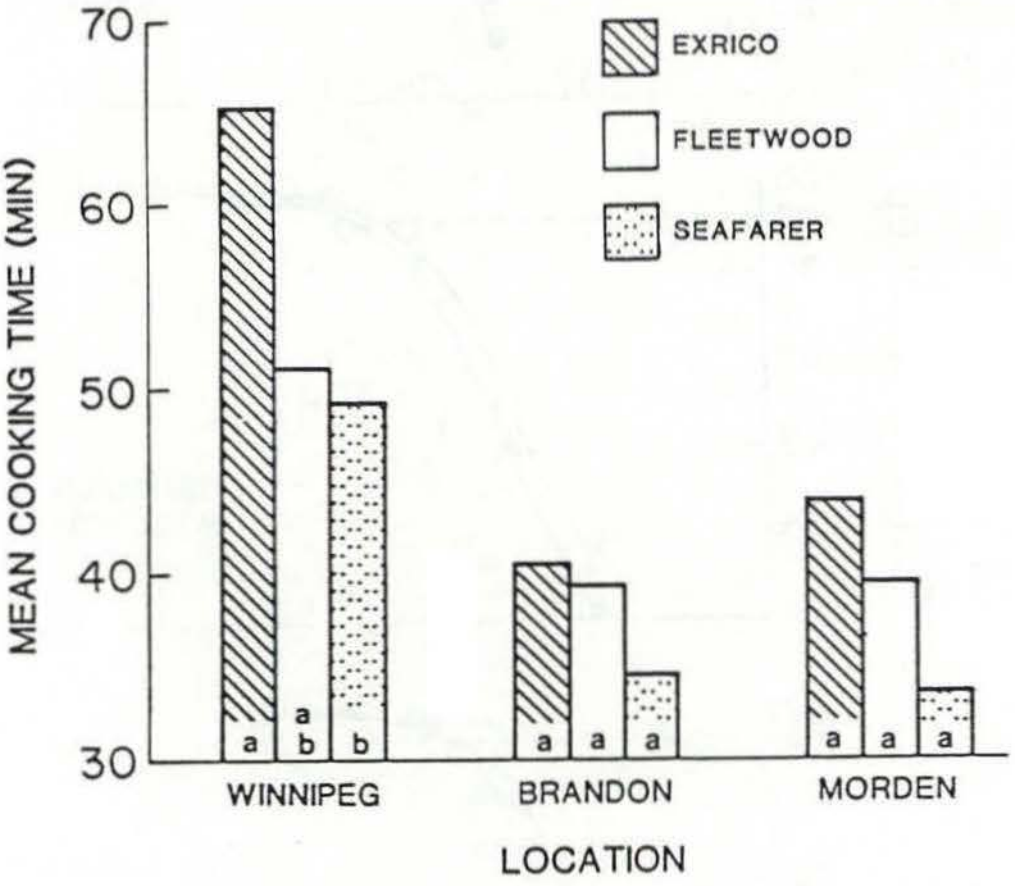


Figure 4-1. Comparison of mean cooking times of three cultivars of navy beans for three locations.

ab means at the same location with the same letter are not significantly different ($P<0.05$) by Tukey mean separation.

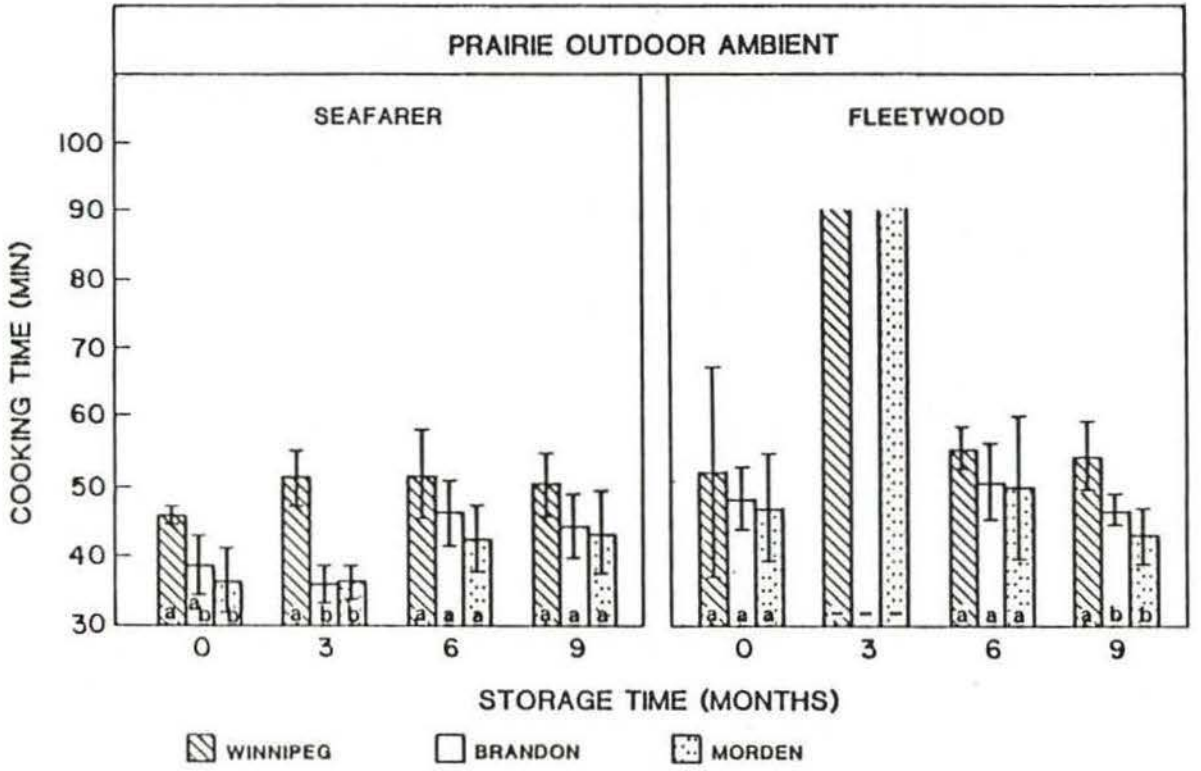


Figure 5-2. Mean cooking times and standard deviations of two navy bean cultivars, grown at three locations, stored under prairie outdoor ambient[1] storage conditions

ab means within a storage time designated with the same letter are not significantly different ($P<0.05$) by Tukey mean separation.

[1]ambient outdoor weather conditions at Winnipeg Manitoba

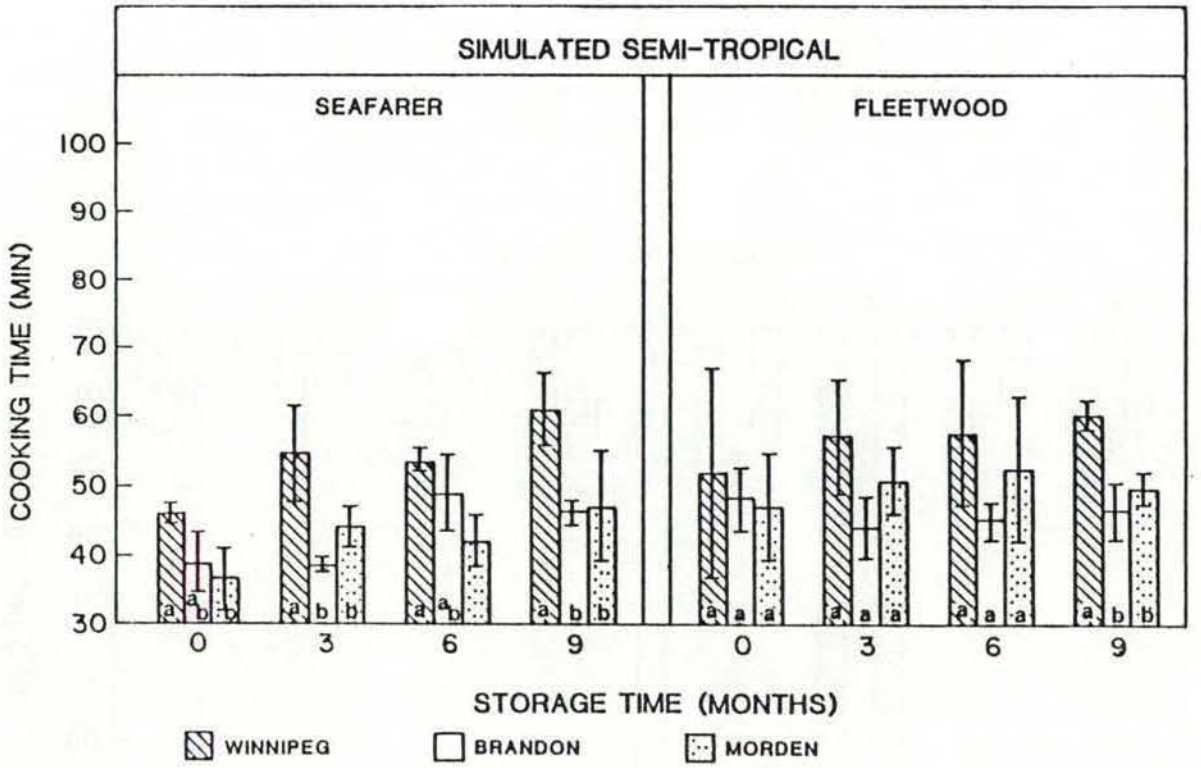


Figure 5-3. Mean cooking times and standard deviations of two navy bean cultivars grown at three locations and stored under simulated semi-tropical[1] storage conditions

ab means within a storage time designated by the same letter are not significantly different ($P<0.05$) by Tukey mean separation.

[1]20 C, 65% R.H.

Lois Jeffery

Procedure for Training a Laboratory Sensory Panel

1. Select a group of interested persons

2. Screen for basic taste and odour acuity

3. Develop a common terminology by use of definitions and examples

4. Evaluate many different types of the product of interest

5. Select most important quality attributes

6. Set-up scales, definitions and standards for evaluation of other similar products

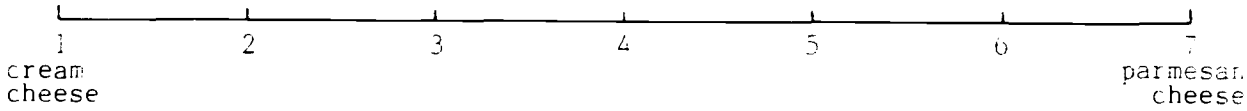
7. Define the standards in physical terms - e.g. hardness (kg force), particle size, so that similar standards can be used in other countries to standardize sensory techniques.

TEXTURE EVALUATION OF BEANS

Using the technique provided in the definitions for evaluating texture, evaluate the samples according to the following parameters. First, evaluate the standard samples to establish reference points, and then evaluate the coded samples and mark the relative intensity of the coded bean samples on each scale.

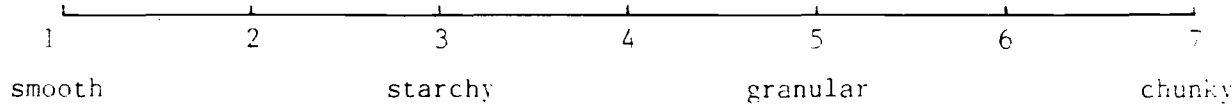
INITIAL BITE

HARDNESS

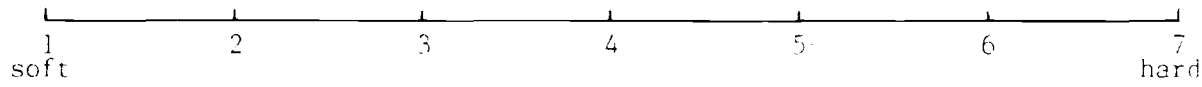


MASTICATORY PHASE

PARTICLE SIZE



SKIN TOUGHNESS



CHEWINESS

Sample code	Number of chews
____	____
____	____
____	____
____	____

DEFINITIONS FOR EVALUATING TEXTURE

HARDNESS - Bite down once with the molar teeth on the sample of beans (2) and evaluate the force required to penetrate the sample.

CHEWINESS - Place a sample of beans (3) in your mouth and chew at a constant rate (1 chew per second), counting the number of chews until the sample is ready to be swallowed.

PARTICLE SIZE - Chew the sample of beans (2) between the molar teeth for 2-3 chews. and then rub the cotyledon between tongue and palate and assess the size of the particles.

SKIN TOUGHNESS - Evaluate the force required to bite through the skin of one bean with the front teeth. Separate the skin from the cotyledon by biting the bean between the molar teeth and rubbing the cotyledon out between the tongue and palate.

FRACTURABILITY - Place a sample of beans (2) between the molar teeth and bite down evenly until the beans crumble or break. The degree of fracturability is the force with which the food breaks.

ORDER OF APPEARANCE OF TEXTURE CHARACTERISTICS

SURFACE

(perceived by feeling with the tongue)

INITIAL

(perceived on first bite)

Mechanical			Geometrical
Hardness	Viscosity	Fracturability	any, depending upon product structure

MASTICATORY

(perceived during chewing)

Mechanical			Geometrical
Gumminess	Chewiness	Adhesiveness	any, depending upon product structure

RESIDUAL

(change made during mastication)

Rate of breakdown	Type of breakdown	Moisture absorption	Mouthcoating

Name: _____
Date: _____

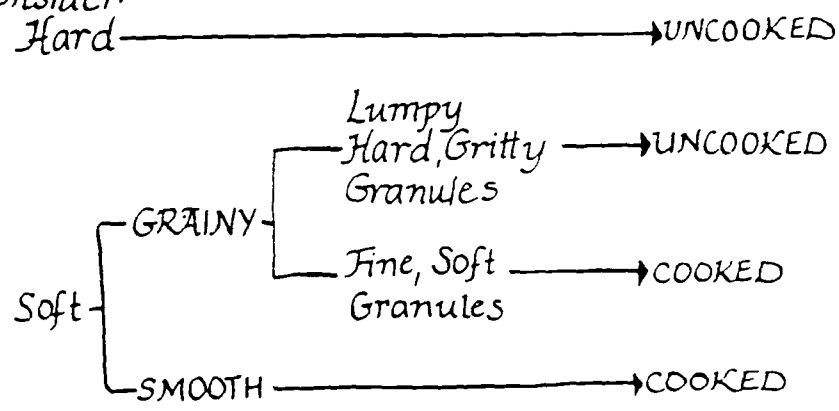
Black Bean Texture

Instructions:
Evaluate 10 beans at random from each sample and record on the ballot the numbers that you consider, according to the following method, are "cooked" or "undercooked".

Method:
1. Place 1 bean between your molars (back teeth) and bite down on it.

2. Press the same bean onto the roof of your mouth with your tongue.

3. Consider:

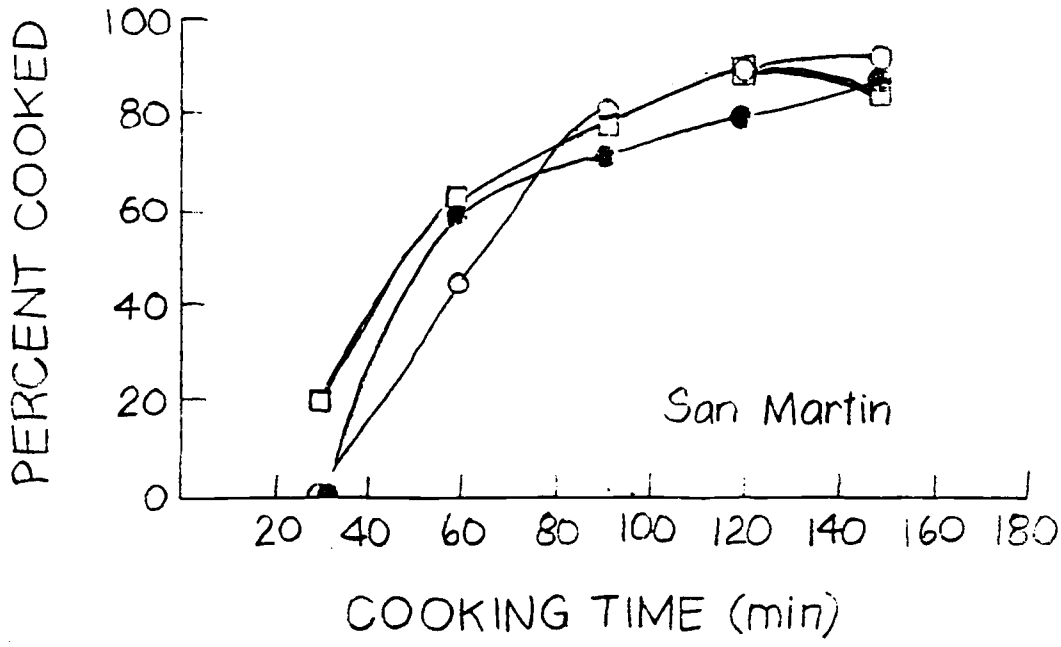


4. Place at least 3 of the remaining beans into your mouth. Chew. Circle the code number of the bean sample that you most prefer **for texture only.**

Sample Code	# of beans UNDERCOOKED	# of beans COOKED

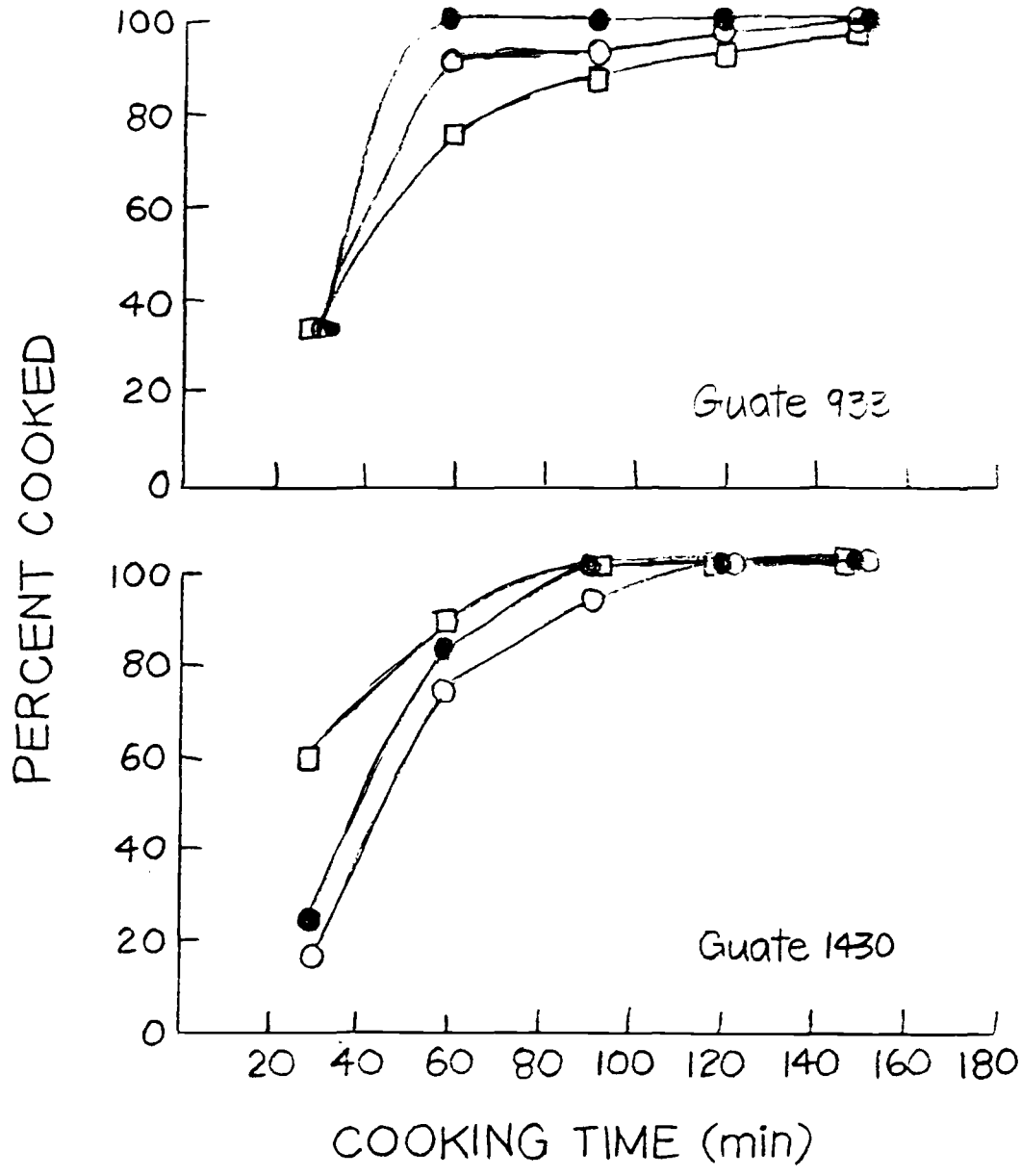
Comments:

Gracias



Cookability curves for "semi-vine" black beans as determined by a sensory panel and by the Mattson Bean Cooker (MBC) using 2 plunger types.

○ - plunger - 85.00 g; 5 mm
● - plunger - 48.50 g; 2 mm
□ - sensory panel



Cookability curves for "vine" black beans as determined by a sensory panel and by the Mattson Bean cooker using 2 plunger types.

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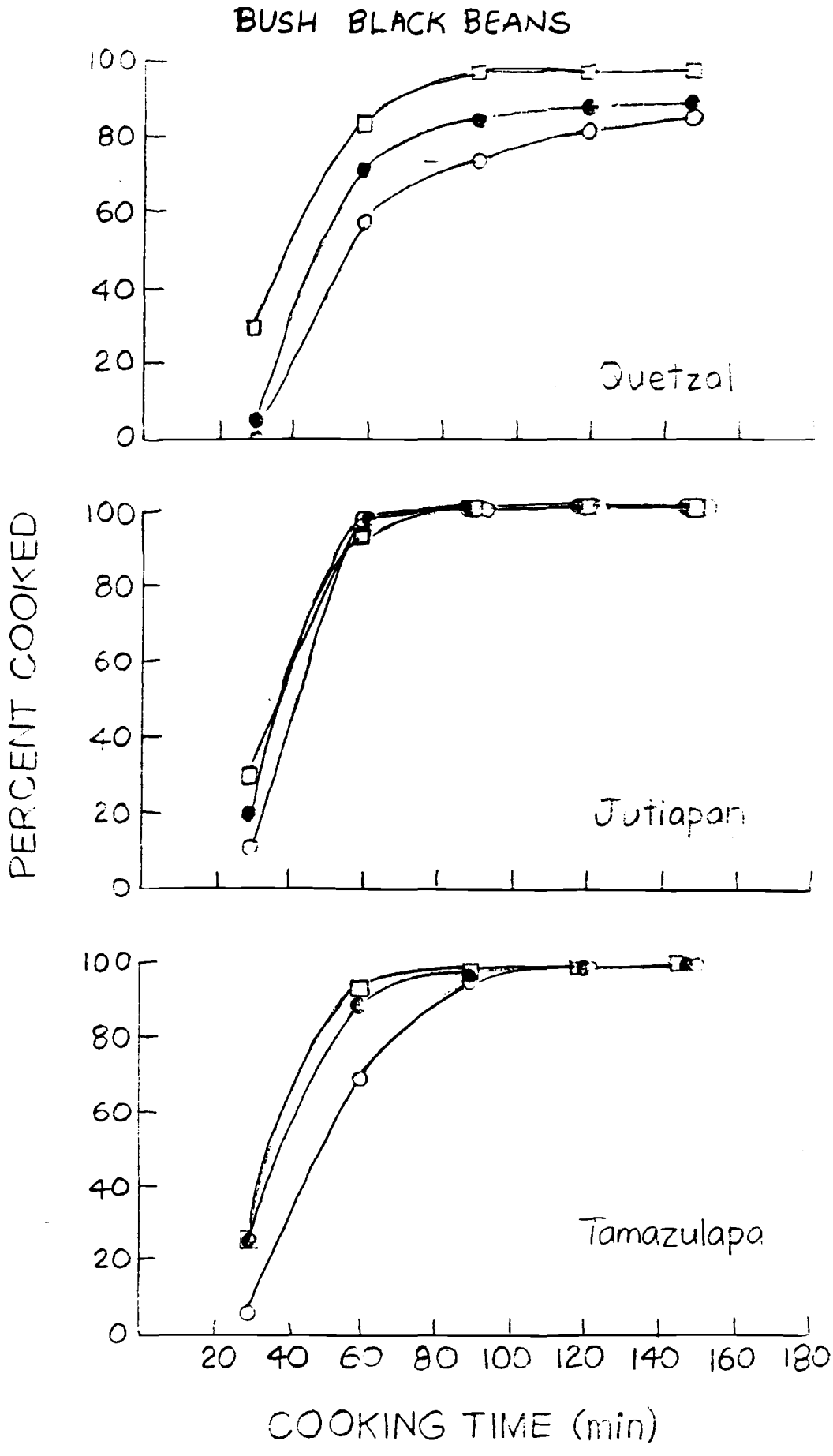

BUSH BLACK BEANS
PERCENT COOKED
100
80
60
40
20
0
Quetzal
Jutiapan
Tamazulapa
20 40 60 80 100 120 140 160 180
COOKING TIME (min)

FOCUS GROUP INTERVIEWS WITH GUATEMALAN CONSUMERS

TABLE OF CONTENTS

INTRODUCTION AND OBJECTIVES

Availability of beans, a staple in the Central American diet, is affected by variable production and poor post-harvest handling. Efforts to introduce new, high-yielding varieties have been impaired by a lack of knowledge of the consumer's criteria of acceptability. Better understanding of these acceptability criteria would benefit agricultural production, breeding, post-harvest technology and nutrition programs.

This preliminary project using the techniques of focus group interviews and observational study was planned to give general information on consumer criteria for acceptability of black beans in Guatemala and on consumer practices. The information provides a basis for a formal consumer survey by permitting the further development of objectives, indicating the range of practices and criteria for judging quality, and suggesting the scope of the questionnaire and the sample choices to be incorporated into the test kit.

The objectives of the preliminary study were: 1) to define the criteria used in the selection of black beans and the characteristics of good eating quality; and 2) to provide information on storage and cooking methods in Guatemalan homes.

METHODS

1. Focus Group Interviews

1.1 Selection of the sample

The areas selected for carrying out the focus group interviews with housewives were 4 administrative departments which, in the judgement of experienced survey workers, would yield information of sufficient breadth to include nearly all aspects of consumer acceptability likely to occur in Guatemala. Characteristics of these areas are described in Table 1.

Contacts were made by means of visits directly to the communities or through departmental capital cities to establish communication with town authorities, institutions and local leaders. Where contacts were made through institutions these are named in Table 1. In the sample were 170 housewives and women who worked outside their homes as teachers, child care workers and cooks. They were interviewed in 28 small informal discussion groups. These focus group interviews were conducted in each area until no new information was being obtained, but if the information was very different from group to group or the message was not clear, more focus group interviews were carried out. The number in each area are indicated in Table 1.

TABLE 1

DESCRIPTION OF SAMPLE FOR FOCUS GROUP INTERVIEWS
(Total number of housewives= 170)

Department	Jutiapa	Chimaltenango	Escuintla	Guatemala City
No. of groups	9	7	4	9
Communities (institutions providing contacts)	Quezada Jutiapa El Progreso Asunción Mita (Home economists of DIGESA) 1/	Patzún (Belhorst Foundation) San Andrés Itzapa (World Vision)	Cuyuta Florida Aceituno (Public Health Ministry and civil authorities)	Bethania Verbena (Public health workers, AMG 2/ and elementary school workers)
Type of area	Bean producing	Bean producing	Non-producing	Non-producing
Lifestyle	Rural and urban	Rural	Rural	Urban
Cultural group	Ladino	Indian	Ladino and Indian	Ladino and Indian
SES	Low	Low	Low	Low and medium
Altitude (m)	900	1,740	355	1,500

1/ DIGESA= General Institution of Agricultural Services.

2/ AMG= Guatemalan Missionary Association

1.2 Conducting the Focus Group Interviews

The respondents gathered at a specified time in convenient comfortable places such as school buildings, health centres, community halls, churches and homes. The interviewers were 2 professional staff members from INCAP. In Indian areas where the women did not speak Spanish, translators were used. The interviewers used a portable tape recorder to record the entire interview. A previously prepared outline of topics to be covered (Guide for Focus Group Interviews) was used by the interviewers to ensure the completeness of the interview. The guide was in the form of a potential questionnaire but was not used in any formal way. At the start of an interview the interviewer was introduced. She explained the purpose of the interview and indicated that the discussion would be recorded to obtain exact information. In the interview many aspects of acceptability, availability, storage, cooking and sensory descriptions were investigated. The women were eager to give information and to partake in the discussions. The average length of interview was one hour. At the end of the interviews, the respondents were thanked and served cakes and coffee or soft drinks.

1.3 Handling the Information

To extract the information from the interviews, the interviewers upon return to INCAP listened to the tape of each interview and using the Guide for Focus Group Interviews, transferred the information into an orderly standardized format. From these records, the information was collated into summaries of information from the 4 departments and an overall summary of this preliminary study.

2. Observations of cooking procedures

2.1 Selection of the sample

To gain information on cooking methods in the homes, a professional INCAP staff member obtained the cooperation of selected respondents in each area to permit observation of the procedures used. Observations were made in 18 homes representing a variety of cultural and socio-economic groups.

2.2 Observation procedures

Housewives were asked to purchase beans of their choice (and were reimbursed) to cook in their usual manner. Notes were taken on each step carried out by the housewife and photographs were taken to help explain some procedures. Samples of raw beans, water to be used for cooking, cooked beans and broth were taken for laboratory analysis.

RESULTS

A great deal of information indicating the variability of practices and range of criteria was gathered by means of the focus group interviews. The information will be reported mainly in descriptive rather than numerical terms because any attempt at quantification would imply a level of accuracy that does not exist. Where data are reported, they serve only as rough indicators.

The results are presented in categories that are descriptive of practices -availability, storage of raw beans, keeping of cooked beans; that report criteria and methods of evaluating quality of raw beans, cooked beans and broth (liquid obtained after cooked beans). These results should make it possible to predict inter-relationships among population characteristics, bean characteristics and consumer practices.

1. Availability

In Jutiapa and Chimaltenango, the respondents were almost equally divided into those from bean producing families and from non-producers. In Escuintla only a few were producers. Most producers grow small quantities of beans, harvesting less than 700 pounds per growing season. The growers keep some for self-consumption, sell some and retain some for seed.

The kind of bean grown is different according to the area. In the highlands (Chimaltenango) it is vine beans because farmers use a corn/bean association agronomic practice. Bush beans are grown in Jutiapa (lowlands) because this is the kind they are accustomed to grow.

All respondents in Guatemala City and most in Escuintla were non-producers. The majority bought beans in markets or in little stores in their towns while a few bought from small farmers, privately owned grain stores or government institutions. In Guatemala City a number of respondents received their beans as gifts from relatives or friends in rural areas.

The housewife is the person who always does the bean purchasing. Housewives buy one to ten pounds per week depending on the size of the family and the age of its members. Of those who purchase beans, the majority buy bush beans because they have better flavor and according to the "hot-cold" food beliefs, do not cause digestive trouble in children. The bush beans are considered a "hot" food and the vine beans a "cold" food.

Several housewives said the vine bean is cheaper than the bush bean while others reported that the two kinds have the same price. They believe that old and hard beans are cheaper. Some housewives said that they thought that price depends on supply. Many housewives said that the best and preferred beans are always available; many indicated that if the preferred beans were not available, they would buy almost always what is available.

2. Storage of raw beans in the home

In Jutiapa and Chimaltenango the beans are stored in larger quantities for longer periods, 4 to 24 months, while in Escuintla and Guatemala City people store from 3 days to 5 months and usually for immediate consumption.

The principal places of storing beans by the families of small farms are the kitchen, the only room of the house or the barn; they prefer a cool dry room. The containers are mainly burlap sacks, metal barrels or wooden boxes. In the non-producing areas, beans are stored in metal pots, paper bags and plastic bags. Other containers used are cans, baskets, wooden casks and plastic barrels.

Some respondents reported that higher quality of beans is maintained by keeping them with some pod residues while others said that it is better to keep them clean.

To keep insects out of the beans in the rural areas, products used

are phostoxin 1/, pholidol 1/, lime, leaves of chilimate 2/ or limoncillo 2/, hot dry peppers and, less frequently, sevin 1/, onion stems, burnt leaves and burnt cattle dung.

3. Raw bean quality assessment

The methods used by consumers to judge the quality of beans at the time of selection and the criteria for good quality appear in Table 2. A slight variation was found from area to area.

4. Methods used in preparation and cooking of beans

The process of preparation and cooking of beans varied a little among the four studied regions. The principal steps carried out by the housewives in this process will be described as follows.

a. Blowing: removal pod residues by blowing or fanning.

b. Cleaning: removal by hand, small stones or malformed grains.

c. Washing: clean the beans using water.

d. Soaking: place raw beans in water for a long time. Only in Guatemala City some housewives soak the beans before cooking, while in other areas (Jutiapa, Chimaltenango and Escuintla) the housewives do not soak them, and they indicated that they use this method only when beans are hard. The informants soak beans during the night, and use the soaking water for the cooking beans.

1/ Insecticides.

2/ Regional trees in Jutiapa.

e. Put the beans into the pot.

f. Addition of water: most respondents said that the quantity of water for cooking beans depends on the amount of raw beans and the capacity of the pot. The majority of informants reported that they add cold water when they start the cooking process while others add hot water to shorten the cooking time. When people add water during the process it must be hot, and indicated that if they add cold water, beans become wrinkled and hard to cook.

g. Addition of other ingredients: the principal ingredients added by the housewives for cooking beans are: salt, onion and garlic, the majority of housewives in the four regions add those ingredients when beans are boiling or when they are cooked, while some housewives add them at the beginning of the cooking process.

The cooking time used by the housewives is 1 1/2 to 8 hours; it was found that this time depends on several factors as: criteria used to determine if beans are cooked, intensity of fire, kind of pot, altitude. According to the last description, it was found that the longest cooking time was reported in Chimaltenango (1,740 m. above sea level) and the shortest was in Escuintla (355 m. above sea level).

Most housewives from the four regions (Guatemala, Escuintla, Chimaltenango, Jutiapa) use clay pots for the cooking process, while others use enamel and aluminum pots and a few use pressure cooker, mainly in the urban areas.

TABLE No. 2

METHODS AND CRITERIA FOR JUDGING QUALITY OF RAW BEANS

Methods	Criteria	
	Good quality	Poor quality
Bite with teeth	soft to bite	hard to bite
Observe hilum color	white	brown or yellow
Observe cotyledon color	white	brown or yellow
Exhale over beans	opaque, blacer	ash-grey
Drop beans over big quantity of them	solid sound	hollow sound
Peel the seeds	hard to peel	easy to peel
Cut with nail	soft	hard
Rub the grains	brillant	opaque

The majority of women reported that they use wood as fuel, while others use gas, especially in the urban areas.

5. Criteria to determine doneness

The criteria to determine doneness was similar in the our studied areas and a complete description is shown in Table 3. This table is self-explanatory.

TABLE 3

METHODS AND CRITERIA USED TO DETERMINE DONENESS OF BLACK BEANS

Methods	Criteria	
	Cooked beans	Not cooked beans
Press the cooked grains with the fingers	soft, smooth, doughy, easy to take apart	hard granular consistency
Observation of physical characteristics of bean grain and bean broth	grains: spongy and broken in the middle. Broth: black and thick	broth: dark, brown
Blow over cooked beans and observe the results	Broken in the middle	not broken in the middle
Measure a standard cooking time	30-45 min. if used in pressure cooker	------

6. Sensory characteristics of beans during cooking and when cooked

All respondents gave information on the sensory characteristics of cooked beans and bean broth, as taste, color, odor, texture, thickness. All information is shown in Table 4. This table is self-explanatory.

TABLE 4

SENSORY CHARACTERISTICS OF BEANS DURING COOKING AND WHEN COOKED

COOKED BEANS				BEAN BROTH	
Taste	Color	Smell	Texture	Thickness	Color
good	black	beany	soft	good quality beans produce:	black
savory	brown	pleasant	bland	thick	dark
				concentrated broth	bush beans: brown broth
Incomparable		good	doughy	poor quality beans produce thin broth	
Beany		depends on the seasonings	starchy		vine beans: black broth
Broady beany			spongy		
Impossible to define		specific and characteristic			
		impossible to define			

Preparation and keeping of cooked beans

The frequency of beans preparation made by women in the investigated areas was from daily to once a week and the respondents reported that it depends on the size of the family, the frequency of bean consumption and on how cooked beans are kept.

All respondents from the four investigated areas informed that the container used to keep cooked beans depends on the kind of pot used in the cooking process; if they use clay pot, this containers will be used to keep the cooked beans, but if the beans were cooked in pressure cooker, they must be changed to another container which could be a plastic or enamel container.

Most women keep the containers with cooked beans in the kitchen, they look for a cool place far from the fire.

All respondents said that the principal methods used to avoid spoiling of cooked beans are: to boil the cooked beans every day, add a certain amount or fat or keep the beans far from the fire.

Observation of cooking procedures

The cooking procedures were similar among the different homes in each region, the general data obtained in the different steps of the cooking process appear in Table No. 5. Is possible observing slight variations within the same department in terms of quantity of raw beans, amount of water, kind or pot, intensity of fire and total cooking time.

Guatemala City and Escuintla are the regions where housewives use largest quantities of raw beans, while in Chimaltenango and Jutiapa, women use less quantities of raw beans (Table 6).

The relationship between quantity of raw beans and amount of initial water is showed in Table 7. Jutiapa is where the housewives use more amount of water in relation with raw beans while in Chimaltenango, the informants use less amount of water in relation with quantity of raw beans.

The longest cooking time was found in Chimaltenango (342 minutes) while the shortest was found in Escuintla and Jutiapa (111-134 minutes). That information appears in Table 8.

An attempt to correlate criteria and methods used at home level with objective methods 1/ in the laboratory indicates that hardness of cooked beans and cooking time of raw beans have an average value of 114.5 g/force

---

1/ Cooking time was carried out in the laboratory using a method based on placing soaked and raw beans in enough boiling water (95°C) for 30, 60, 100, 140, 180 minutes. Twenty-five seeds were taken for every cooking time, cooled to room temperature, and hardness of each seed was measured in the DUR-INCAP instrument (designed and constructed in the Division of Agricultural and Food Sciences at INCAP).

and 116 minutes, respectively. A value of 94.13 g/force was found for the cooked samples indicated by the housewife as the ones they prefer for consumption. Previous studies indicate that a value of about 100 g/force corresponds to the texture accepted by a consumer's panel. Thickness of the broth measured either as viscosity or % of solids was also higher (0.0480 and 13.41%) than the average values (0.0369 and 10.01%). This information appears in Table 9.

TABLE No. 5

DATA OBTAINED IN OBSERVATIONS OF COOKING PROCEDURES
STUDY ON UTILIZATION OF BEANS. GUATEMALA. 1985

Department	Community	Quantity of raw beans (g)	Initial water (cc)	Water added during process (cc)	Temperature of water Start	Temperature of water Process	Seasonings	Container and fuel	Intensity of fire	Cooking time	Methods to determine doneness
Jutiapa	La Pava	688	3340	1310	25	25	Salt, garlic	clay, wood	direct	1 h. 54 minutes	Observation of beans and broth; press a grain with the fingers
		460	1720	1780	72	22	Salt, garlic onion	clay, wood	direct	1 h. 55 minutes	Press a grain with the fingers; taste a grain and determine softness
	La Flor ✔	530	2500	600	22	22	salt	clay, wood	direct and slow	2 h. 57 minutes	Blow or fan over grains; if they are broken, they are cooked
		478	2070	820	35	35	salt, garlic	clay, wood	indirect	2 h. 10 minutes	Press a grain with the fingers; observe color of the cooked grains
	Asunción Mita	800	2300	---	27	--	salt, garlic	pressure cooker, gas	direct high	20 minutes	Taste a grain to determine softness Press a grain with the fingers
Chimaltenango	Patzún	320	740	637	30	22	salt, garlic apazote, onion	clay, wood and corn cobs	indirect	6 h. 41 minutes	Observe color and thickness of the broth. Press a grain with the fingers
		513	900	2145	65	55	salt, garlic onion	clay, wood	direct indirect	5 h. 20 minutes	Observe characteristics of grains Press a grain with the fingers
		475	900	2187	18	18	salt, garlic onion, apazote	clay, wood	direct	6 h. 48 minutes	Observation of grains and broth. Press a grain with the fingers
	San Andrés Itzapa	680	1360	1320	40	25	salt, onion garlic, apazote	clay, wood	indirect	7 h. 17 minutes	Press a grain with the fingers
		458	1080	2320	18	40	salt, garlic	clay, wood	direct	3 h. 50 minutes	Observation; press a grain with fingers
		460	1130	2630	30	30	salt, garlic onion with	clay, wood	indirect	4 h. 15 minutes	Press a grain with the fingers
Guatemala		1095	4230	1220	19	19	salt, apazote	enamel pot wood	indirect	3 h. 38 minutes	Observation of characteristics and color of the grain. Press a grain with the fingers
		670	2600	3320	42	42	salt, garlic onion	clay, wood	direct	4 h. 50 minutes	Press a grain with the fingers. Observe the thickness of the broth

.../

Department	Community	Quantity of raw beans (g)	Initial water (cc)	Water added during process (cc)	Temperature of water Start	Temperature of water Process	Seasonings	Container and fuel	Intensity of fire	Cooking time	Methods to determine doneness
Escuintla	Cuyuta	450	500	990	26	29	Salt, onion	clay, wood	indirect	3 h. 25 minutes	Blow or fan over the beans. Press a grain with the fingers
		695	1800	500	28	30	Salt, garlic onion	enamel pot, wood	indirect	1 h. 42 minutes	Observation of characteristics of the grain. Press a grain with the fingers
	Florido	700	3140	----	78	--	salt, garlic onion	clay, wood	direct	1 h. 25 minutes	Observation of grains and broth
		480	1600	1000	27	27	salt, garlic onion	clay, wood	direct	2 h. 20 minutes	Press a grain with the fingers Observation of characteristics of the grain
		830	2000	2000	27	27	salt, garlic onion	clay, wood	direct	2 h. 20 minutes	Observation of color of the broth Press a grain with the fingers

TABLE 6

QUANTITY OF RAW BEANS USED BY THE HOUSEWIVES
OBSERVATIONS OF COOKING PROCEDURES

Region	Quantity (g)
Escuintla	631 (450 - 830)
Guatemala City	883 (670 - 1095)
Chimaltenango	486 (320 - 680)
Jutiapa	592 (460 - 800)
General average	600 (320 - 1095)

TABLE 7

QUANTITY OF RAW BEANS, AMOUNT OF INITIAL WATER AND RELATION BETWEEN BEANS: INITIAL WATER, USED BY HOUSEWIVES IN OBSERVATIONS OF COOKING PROCEDURE

Region	Raw beans (kg)	Water (lts.)	Relation Beans:water (kg) (lts.)
Escuintla	0.631	1.808	1:28
Guatemala City	0.882	3.415	1:3.90
Chimaltenango	0.486	1.018	1:2.13
Jutiapa	0.592	2.386	1:4.10
General Average	0.600	1.913	1:3.22

TABLE 8

COOKING TIMES USED BY HOUSEWIVES
OBSERVATIONS OF COOKING PROCEDURES

Region	Time (Minutes)
Escuintla	134
Guatemala City	254
Chimaltenango	342
Jutiapa	111
General average	210

TABLE 9

LABORATORY EVALUATION OF THE COLLECTED SAMPLES

	Water pH	Cooked beans hardness (g-F)	Raw beans cooking 1/ time (min.)	Broth	
				Viscosity 2/ (m.)	Solids %
Average (16 samples)	6.71	114.5	116	0.0369	10.01
Average (3 samples) Cooked as they like to eat it		94.1	--	0.0480	13.41

1/ Cooking time to reach 100 g/force.

2/ Brookfield viscosimeter (lb/feet/sec.)

SUMMARY

The focus group interviews showed that availability of black beans and storage practices in the homes varied between producing and non-producing regions. The criteria and methods used for evaluating quality varied slightly throughout the sample. Good quality raw beans are generally those that are very black, soft to bite and have white hilum and cotyledon. Good quality cooked beans have a very smooth texture and skin that desintegrates so that it is not detectable in the mouth. The broth should be thick and very dark in color.

The observational study was particularly useful in giving details of amount of water, cooking temperature and time, added ingredients, kind of cooking pot, type of stove and fuel and methods of evaluating doneness.

CONCLUSIONS

The qualitative techniques y yielded valuable information to guide the laboratory tests in terms of methods that can be related to home cooking practices and consumer criteria of quality. The information provides a good basis for designing the formal survey and elaborating the details of the questionnaire. The survey will elicit hard data to verify the results of the qualitative techniques.

PAGE

APPENDIX III

Papers presented by guest participants

EXPERIENCES OF THE GRAIN AND SEED RESEARCH CENTER ON THE COOKING TIME OF BEANS (Phaseolus vulgaris L.)

Miguel A. Mora

University of Costa Rica, Grain and Seed Research Center (CIGRAS)

CONTENTS

INTRODUCTION

Costa Rica, as a country that produces and consumes beans, has not escaped the problem of avoiding the increment of the cooking time during storage and when this occurs, the enigma of what to do with these beans arises.

Due to the importance of this problem CIGRAS has been working for the past 4 years on different aspects in relation to this topic. The research has been studied in a general sense in order to acquire more information and knowledge on the probable factors involved in this phenomena hoping that this information will help us minimize the severity of this problem. Some of the factors that have been studied are: temperature, moisture content, seal storage and heat treatments. On the other hand, in order to obtain better results the method of analysis was also evaluated.

In the following pages a compendium of the results found in the research will be stated.

METHODS OF ANALYSIS

In all of our research the method used for evaluating the cooking time has been that of maintaining a sample of beans in boiling water until they are cooked. In order to determine the time necessary for the beans to be cooked a sample of 100 beans are taken periodically and each bean is pressed between two fingers. The number of cooked beans is expressed in percentage of all the beans analysed. A bean is considered to be cooked when it is pressed between two fingers and it squeezes easily taking into consideration that hard pieces should not be present.

There are some posible differences in the methodology and for that reason

some tests were conducted and the results will be expressed further on.

The moisture content was determined by utilizing an oven with forced air at 103ºC during 72 hours in which samples of whole beans were put in.

Final Cooking Percentages

In order to obtain the cooking time, one for the most important is the percentage of cooked beans.

In certain occasions the cooking time has been defined as the time necessary to cook 50% of the beans in the sample for the reason that this moment can be more easily identified.

In other definitions the cooking time used is determined when 90% of the sample is cooked, considering that between this percentage and 100% the time lapse is considerably short and therefore, the results in the test are not affected.

In the evaluation method the cooking percentages that we have used; we found that in certain occasions the relative positions of the treatments in a test are different if they are evaluated in 50, 90 and 100% cooking times (Figs. 1 and 2). For this reason and based that in the practice our main interest is to know the time necessary to prepare the beans for human consumption therefore we prefer to consider the cooking time as the time necessary to have 100% of the beans cooked.

Source of heat, quantity of beans and water

Other factors that are mentioned as possible sources in the differences of the results are: the source of heat, quantity of beans and quantity of water used in the sample.

In a test that we realized using different sources of heat (gas and electricity) and different energy liberation intensities the results indicated no special differences in respect to the cooking times, (Table 1).

In this test different amounts of beans and water were also analysed, showing no differences in the results.

Although, since the initiation of the research it might have seem obvious, the results obtained from this test indicate that what is really important is to maintain a sufficient amount of the sample in boiling water in order to be able to do the different cooking percentage evaluations.

Quality of water (hardiness)

Although it has been established that the cooking trials should be done with distilled water, in real life and specially when these trials are conducted for marketing purposes tan water is used. The water contains different salts at various concentrations and therefore, the results in the cooking test could be affected. In our trials (Table 1) the water with 490 ppm, between $CaCO_3$ and $MgSO_4$ the cooking time increased considerably.

Our experiences with salts are insufficient in order to explain the effect in an adecuate way however, we consider that this factor should be kept in mind in the cooking tests.

Altitude

The cooking trials, were conducted in different locations which vary in altitude. The altitude among other factors, affects the atmospheric pressure and therefore, alters the boiling temperature of water. At the moment the boiling temperature of water is varied the results of the cooking trials are

are also affected.

In order to determine the effect of the altitude on the boiling temperature different trials were conducted at various altitudes using the same sample of beans subdivided by zones.

The results indicate that the cooking time for a sample increases in a linear pattern in relation to the altitude of the site where the test is conducted. (Fig. 3).

Analists

Although this factor is of a different nature, due to the manner the test is being conducted the analysis may result biased. It is necessary to consider that the results obtained by different analysts may show important differences and therefore, this effect should be avoided.

FACTORS THAT INFLUENCE THE COOKING TIME

Since exists an interaction between different factors that influence the changes in the cooking time of beans, it is difficult to separate the effect of each of the factors on the trails. However, trying to have a better understanding of their effect, they are presented separately here.

Storage period

It is known that the increment in the cooking time is a phenomena which occurs over a long period of time. The velocity in which this increases is conditioned by various factors such as the moisture content of the grain and the temperature of the storage room.

In our experiences, depending on other conditions, we have found that

the cooking time increases significantly after three months of storage (Table 2) while in other cases after 18 months the beans remain as the original sample. In normal conditions of handling and storage, temperatures of 25ºC and moisture contents of 14% or less have not shown any changes before 6 months of storage.

In respect to the storage period in Fig. 4 the results of the trial indicate a normal increment in the cooking time in relation to the time of storage however, in aun unexpected pattern the cooking time decreased. We do not have a explanation for this behavior best we think it is important to mention it to illustrate the complexity of this problem.

Moisture Content

In our trials the moisture content of the grain generally were 13 and 16%, trying to have a normal storage moisture content and a relatively high moisture content on which the factors tested could be easier manifested.

The general effect of the moisture content was what we expected in other words, the change was greater in beans with a higher moisture content. We notice that moisture contents of 16%, which are considered high, did not show time increments greater than 30 minutes during the 6 months storage period if the temperature was 25ºC or below (Fig. 4, Table 4), or even more in certain cases when the beans were store for 1 year (Tables 3 and 5).

Temperature

The storage temperature, as well as the moisture content, demonstrated that stored at high temperature reach a greater cooking time (Fig. 4, table 6). It is very notable (Table 6) the influence of the temperature on the

cooking time of beans. For example, when red beans with 14.5% moisture content are store for 6 months at 25ºC, the cooking time increments in 30 minutes; at 30ºC the cooking time increments in 60 minutes and at 35ºC the increments is of 130 minutes. After 18 months the cooking time increments were of 100, 150, 340 and 750% in relation to the initial sample. In other words, the effect of equal increments in temperature (5ºC in this case) is greater at higher temperature than at low ones.

Cultivar

In order to more fully understand the cooking time phenomena we usually included cultivars of seed color (read and black), in our tests.

The results indicate that there is not a definit tendency when comparing two cultivars of different seed color. In certain cases the cooking time for the black beans incremented at a faster speed and in other cases the red beans acted in the same manner.

The effect of cultivars was also specifically tested (Table 3), was not evident in our results. In this research others factors which might influence the cooking time were maintained standard. The results show very little effect, if any, of the cultivars on the cooking time changes.

Heating of the bean

Dr. Molina from INCAP and colaborators, found that if the beans were exposed to heat before storage, the increment in the cooking time could be considerably reduce. Therefore, we conducted a test with beans at 18% moisture content exposed to an hair current at 125ºC during 0, 3, 6, 9, 12 and 15 minutes. After the heat treatment, the beans were stored at 14.5% moisture and 25ºC during 18 months

Under these conditions no differences were encountered between treatments. Against the expected beans which were not treated with heat before storage had a shorter cooking time than the ones exposed to heat.

In relation to the effect of heat, beans that were dried from 18% to 16 and 13% using air at 25, 35, 45, 55 and 65ºC, showed a trend that the dried at higher temperatures had slightly higher cooking time (Table 4).

Our results, however, are not conclusive enough to assure that heat applied under certain circunstances can not reduce the cooking time increment.

Seal Storage

Due to the possibility that some external and un known factors might be influencing the cooking time of beans, a test was conducted to study the effect of seal storage on the cooking time of beans. The practice of using seal storage in beans is very commun among small farmers and researchers.

In Fig. 5 the results of the test can be observe and the data demonstrated that there aren't any differences between seal and open storage.

EFFECT OF THE COOKING TIME ON THE NUTRITIONAL QUALITY OF BEANS

Research involving the feeding of laboratory rats

The research included the feeding of laboratory rats with diets in which beans cooked for 60 minutes or until they were soft were used.

The results (Table 7) demonstrate two main factors:

1. Beans of Class I (red or black) which required less cooking time to reach 100% cooking, had a better nutritional quality when they were cooked during 160 or 280 minutes than when cooked for 60 minutes.

2. When the beans were cooked during 220 or 340 minutes or more the nutritional quality of the beans was less. With cooking times as long as 410 or 490 minutes (7-8 hours) the lost in the nutritional quality was aproximately 40%.

Table 1. Effect of differences in the method of analysis on the cooking time of two lots of beans.

VARIABLE		NEW BEANS	OLD BEANS
Amount of:			
Sample (g)	Water (ℓ)		
200	1	63*	137
200	2	60	143
200	3	63	133
400	1	70	140
400	2	60	130
400	3	60	133
600	1	73	143
600	2	73	133
600	3	63	133
Source of heat	Intensity		
Electricity	Low	70	150
Gas	Low	80	150
Electricity	high	70	140
Gas	high	70	150
Gas	maximun	73	140
Hardness of water			
		73	147
250 ppm		73	137
490 ppm		77	197
Altitude**			
20		63	103
920		70	140
1800		83	197

* Cooking time (minutes). Average of three repeticions.

**meters above sea level

Table 2 Effect of heat on the increment of the cooking time of beans.

COLOR OF BEANS	EXPOSURE MINUTES AT 125ºC	STORAGE PERIOD (months)						
		0	3	6	9	12	15	18
RED								
	0	60	71	86	101	105	113	120
	3	60	68	98	109	124	139	150
	6	60	79	105	116	113	128	146
	9	60	83	90	105	139	143	158
	12	60	79	101	105	120	131	139
	15	60	83	101	120	128	135	143
BLACK								
	0	60	78	98	98	98	105	116
	3	60	75	101	105	116	128	131
	6	60	75	105	105	113	124	135
	9	60	86	101	113	120	131	139
	12	60	86	105	116	113	120	135
	15	60	90	105	116	128	131	139

NOTE:

1. Heat treatment at 18% moisture content.
2. Storage 25ºC with 14.5 moisture content

Table 2. Effect of heat on the increment of the cooking time of beans.

COLOR OF BEANS	EXPOSURE MINUTES AT 25ºC	STORAGE PERIOD (months)						
		0	3	6	9	12	15	18
RED								
	0	60	71	86	101	105	113	120
	3	60	68	98	109	124	139	150
	6	60	79	105	116	113	128	146
	9	60	83	90	105	139	143	158
	12	60	79	101	105	120	131	139
	15	60	83	101	120	128	135	143
BLACK								
	0	60	78	98	98	98	105	116
	3	60	75	101	105	116	128	131
	6	60	75	105	105	113	124	135
	9	60	86	101	113	120	131	139
	12	60	86	105	116	113	120	135
	15	60	90	105	116	128	131	139

NOTE:

1. Heat treatment at 18% moisture content.
2. Storage 25ºC with 14.5 moisture content

TABLE 3. Effect of cultivar on cooking time (minutes) of beans.

CULTIVAR	MOISTURE CONTENT AT STORAGE (%)	STORAGE PERIOD AT 25ºC (months)						
		0	3	6	9	12	15	18
RED								
México 80	13	60	60	70	75	77.5	90	110
Corobicí	13	60	60	65	70	80	90	95
Chorotega	13	60	60	60	65	80	90	96
Huetar	13	60	60	70	75	82.5	95	115
México 80	16	60	60	75	88	105	135	150
Corobicí	16	60	63	70	90	98	135	150
Chorotega	16	60	63	65	87	90	115	145
Huetar	16	60	75	75	90	105	150	185
BLACK								
Pavamor	13	60	60	60	73	77.5	100	120
Brunca	13	60	60	60	70	77.5	87.5	92.5
Porrillo sintético	13	60	60	63	80	82.5	102.5	105
Talamanca	13	60	63	70	74	80	95	105
Pavamor	16	60	60	67.5	90	102.5	115	150
Brunca	16	60	60	62.5	88	90	103	115
Porrillo sintético	16	60	60	75	90	110	135	143
Talamanca	16	60	63	75	90	105	135	158

Table 4 Cooking time (minutes) of red and black beans dried at different temperatures and stored at 13 and 16% moisture content at 25 + 2°C during 18 months*.

Color	Moisture Content (%)	Drying °C	STORAGE PERIOD (months)					
			0	3	6	9	12	15	18
RED	13	SL	60 U	71 RSTU	68 STU	75 QRSTU	64 TU	75 QRSTU	83 OPQRS
	13	35	60 U	64 TU	64 TU	68 STU	71 RSTU	71 RSTU	75 QRSTU
	13	45	60 U	64 TU	60 U	79 PQRST	60 U	68 STU	79 PQRST
	13	55	60 U	60 U	60 U	75 QRSTU	75 QRSTU	68 STU	75 QRSTU
	13	65	60 U	60 U	75 QRSTU	90 MNOPQ	75 QRSTU	75 QRSTU	90 MNOPQ
	16	SL	60 U	64 TU	71 RSTU	75 QRSTU	94 LMNOP	98 KLMNO	113 GHIJK
	16	35	60 U	68 STU	75 QRSTU	98 KLMNO	90 MNOPQ	94 LMNOP	120 EFGHI
	16	45	60 U	64 TU	75 QRSTU	101 JLKMN	90 MNOPQ	113 GHIJK	124 EFGH
	16	55	60 U	60 U	79 PQRST	90 MNOPQ	90 MNOPQ	113 GHIJK	131 DEF
	16	65	60 U	60 U	86 NOPQR	105 IJKLM	105 IJKLM	116 FGHIJ	143 CD
BLACK	13	SL	79 PQRST	83 OPQRS	83 OPQRS	101 JKLMN	98 KLMNO	105 IJKLM	109 HIJKL
	13	35	86 NOPQR	105 IJKLM	86 NOPQR	86 NOPQR	98 KLMNO	98 KLMNO	105 IJKLM
	13	45	83 OPQRS	86 NOPQR	90 MNOPQ	105 IJKLM	109 HIJKL	98 KLMNO	105 IJKLM
	13	55	90 MNOPQ	101 JKLMN	86 NOPQR	105 IJKLM	105 IJKLM	105 IJKLM	113 GHIJK
	13	65	86 NOPQR	105 IJKLM	86 NOPQR	94 LMNOP	109 HIJKL	116 FGHIJ	128 DEFG
	16	SL	86 NOPQR	105 IJKLM	105 IJKLM	113 GHIJK	131 DEF	120 EFGHI	154 BC
	16	35	75 QRSTU	94 LMNOP	101 JKLMN	105 IJKLM	120 EFGHI	128 DEFG	150 C
	16	45	83 OPQRS	98 KLMNO	94 LMNOP	113 GHIJK	135 DE	128 DEFG	150 C
	16	55	86 NOPQR	105 IJKLM	113 GHIJK	124 EFGH	135 DE	128 DEFG	165 B
	16	65	79 PQRST	101 JKLMN	101 JKLMN	143 CD	143 CD	131 DEF	185 A

* Initial moisture content 18%

Results with at least one letter in common are not different (P=0.05)

Table 6. Effect of the temperature on the cooking time (minutes) of beans stored during 18 months at 14.5 moisture content.

MONTHS OF STORAGE	COLOR OF THE BEANS	STORAGE TEMPERATURE (°C)			
		20	25	30	35
0	RED	60	60	60	60
	BLACK	60	60	60	60
3	RED	75	60	90	112
	BLACK	75	75	82	105
6	RED	82	90	120	190
	BLACK	90	90	97	180
9	RED	90	105	135	220
	BLACK	90	90	120	202
12	RED	97	105	165	240
	BLACK	90	112	150	210
15	RED	105	127	195	300
	BLACK	105	127	172	240
18	RED	120	157	210	450
	BLACK	112	142	202	375

Table 5. Cooking time (minutes) of black beans treated with heat and stored at 25ºC during 12 months with moisture contents of 13 and 16%.

MOISTURE CONTENT (%) DURING		MINUTES OF TREATMENT AT 125 C			
TREATMENT	STORAGE	0	2	4	6
16	13	75	75	75	75
16	16	75	75	75	82.5
13	13	75	75	75	75
13	16	90	90	90	90

Note: The initial cooking time was 60 minutes.

Table 7. Effect of the cooking time of beans on the feeding of laboratory "rats".

TYPE OF BEAN[1/]	COOKING TIME (100%) Min.	DIFFERENCES OF WEIGHT GAIN (in percentage)[2/]
RED		
1	160	11.6
2	220	-28.5
3	320	-23.4
4	410	-41.4
BLACK		
1	280	11.8
2	340	-37.0
3	390	-37.4
4	490	-42.2

1/ Bean stored at 25ºC during 18 months with different moisture contents:

Group 1. 11% moisture content.
Group 2. 13% moisture content.
Group 3. 15% moisutre content.
Group 4. 17% moisutre content.

2/ Differences of weight gain at 10 days when the rats were fed with beans cooked 1 hour agaist beans cooked completely (to 100%). Results expressed as percentages of the weight obtained with the beans cooked 1 hour

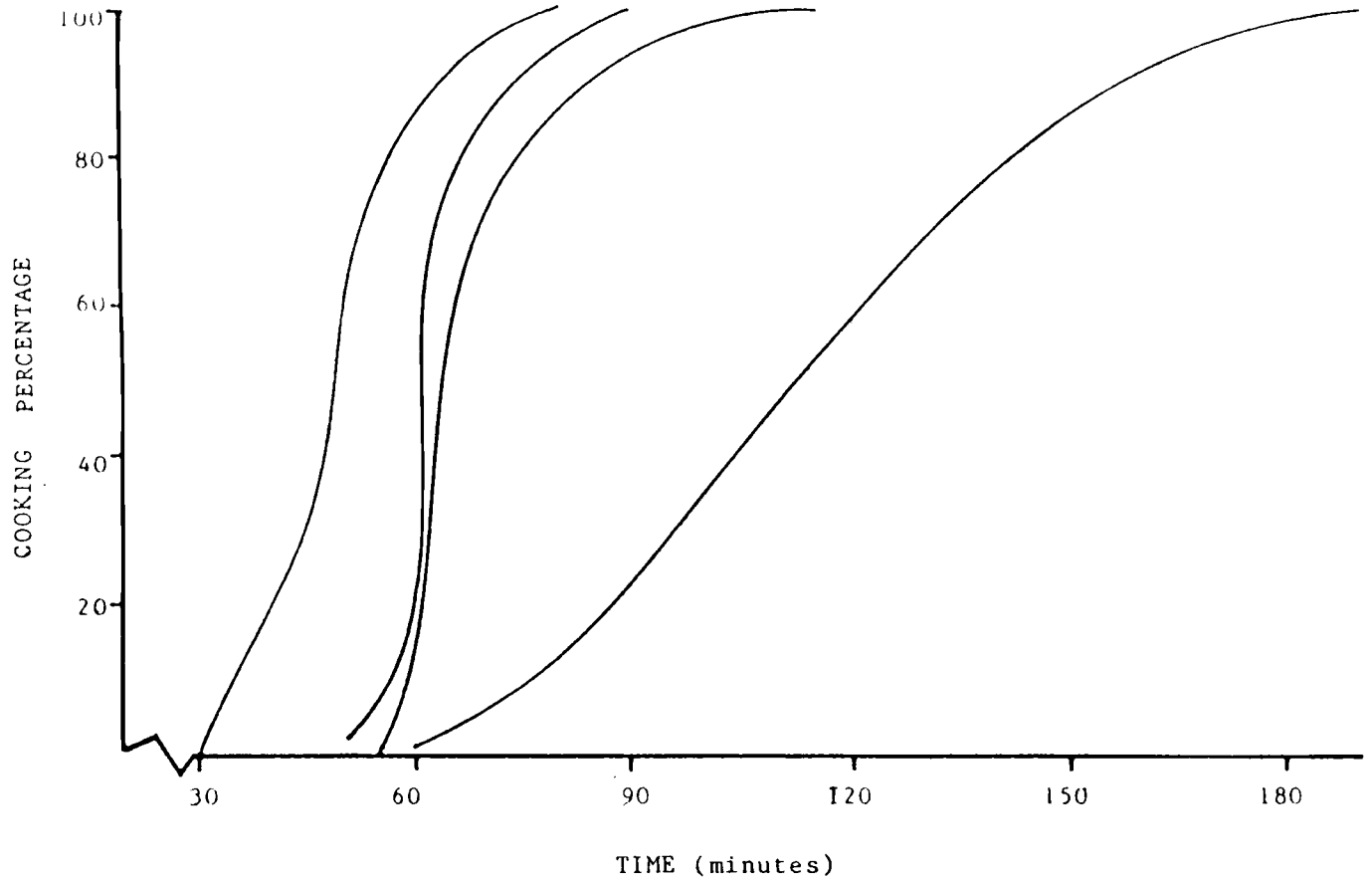


Fig. 1. Percentage increments of cooked beans in 4 samples.

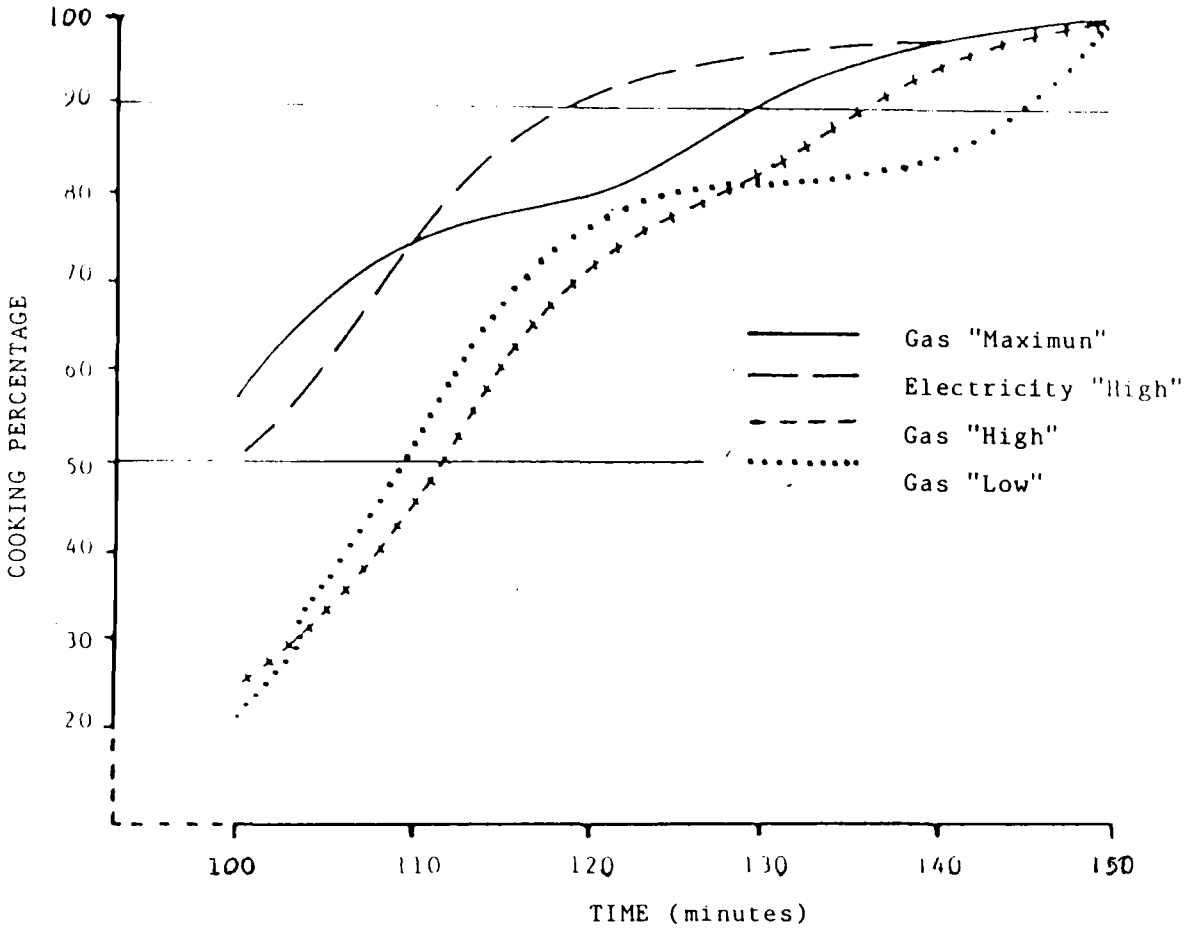


Fig.2 Cooking percentages in relation to the duration of the test.

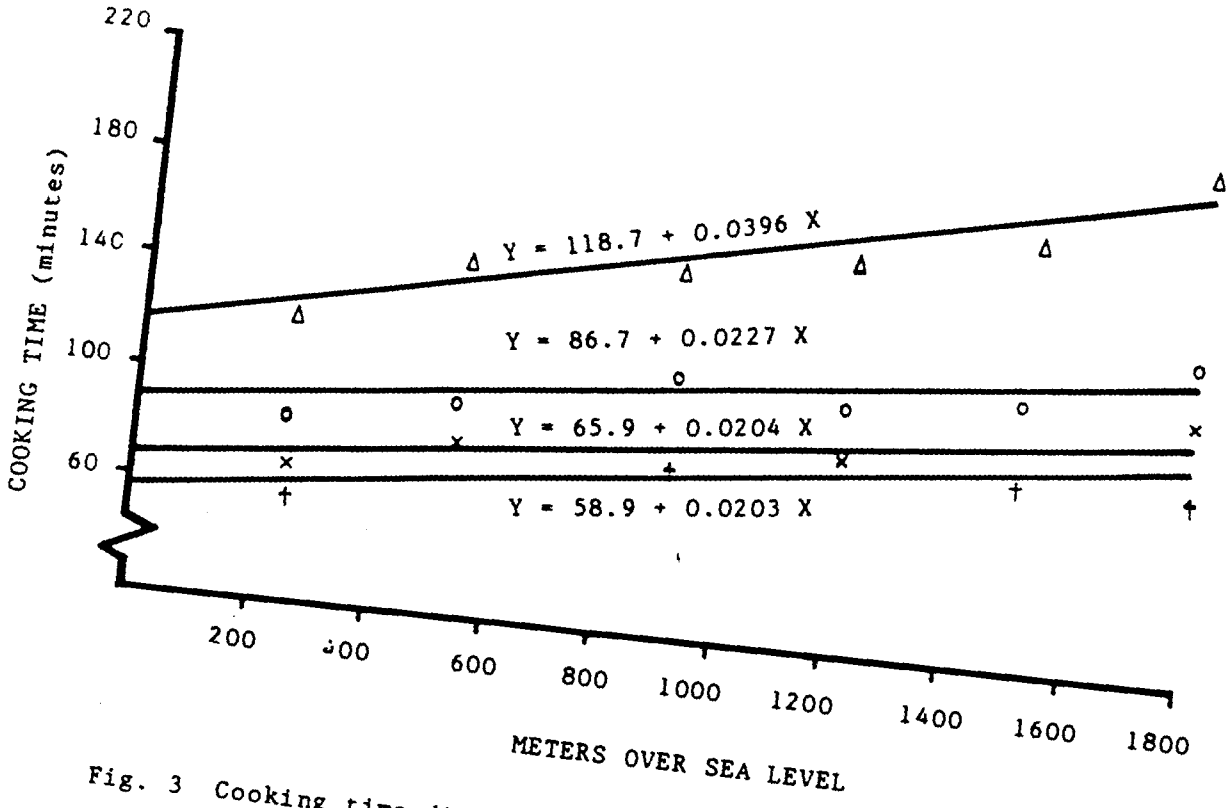


Fig. 3 Cooking time differences of four lots of beans in relation to the altitude where the test was conducted.

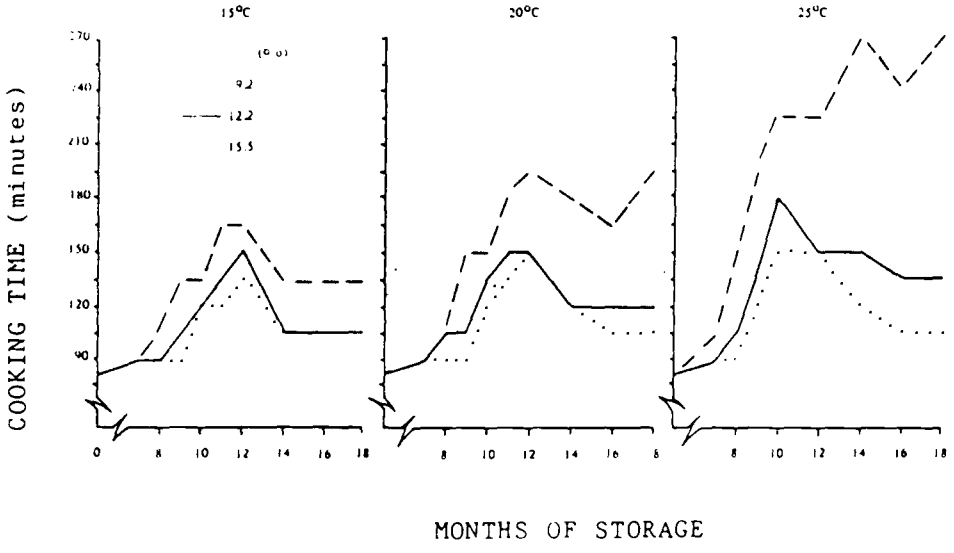
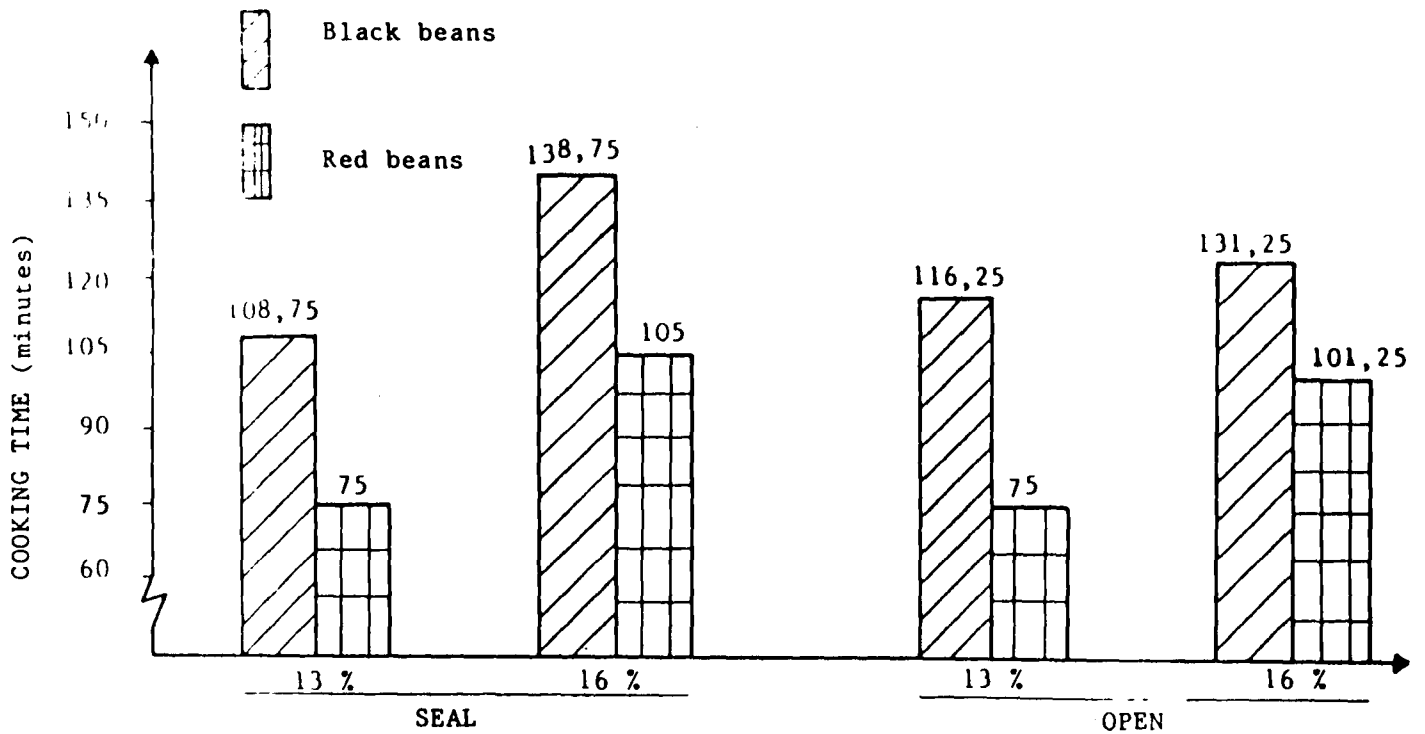


Fig. 4 Cooking time of black beans (Phaseolus vulgaris) stored at three moisture contents and three temperatures during 18 months.



Cook time of beans after 12 months of storage at 25ºC.

Fig. 5 Effe t of seal storage on the cooking time of beans after 12 months of stor ge at 13 and 16% moisture content and 25ºC.

SUMMARIES OF MAJOR STUDIES CARRIED OUT IN BRAZIL ON BEAN HARDENING

MARIA REGINA SARTORI

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STORAGE OF DRY BEANS IN INDUSTRIAL SCALE IN SILO WITH FORCED AERATION

B.A.JORDÃO, G.R.CARVALHO, M.R.SARTORI, E.ANGELUCCI, M.F.F.LEITÃO, S.I.COSTA e E.E.MIYA

In: Coletânea do Instituto de Tecnologia de Alimentos 7:265-298, 1976

Dry beans var. Carioca produced during the dry season of 1974, was dried to 13.75% and stored during 12 months in two metal cylindrical bins (2m in diameter and 6m in height) belonging to the silo of the Storage Section of ITAL, being one with forced aeration ($10m^3$/ton/h) and one without aeration, in bags in warehouse and in bags in a controled chamber at 10 - 15°C and 50 - 60% R.H. The climatic conditions during the storage period was 24°C and 63% R.H. The aeration was controlled by a termostat and a humidistat to operate only when the temperature was less or equal to 18°C and around or lower than 70% R.H. Samples were taken at 4 months intervals and submited to the following tests: moisture content, specific density, fiber, ash and reduced sugars, iron, protein dispersibility index (P.D.I.), protein, acidity (F.F.A.), total mesophilic count, mold and yeast count insect infestation, germination, sensorial evaluation, texture and color.

The aeration under the conditions described kept the moisture content of the beans, during 12 or more months of storage, around 12%, controlled mold and insect development, and contribute to increase the ratings attributed by the panelists during sensorial evaluation. After 12 months storage the flavor texture and preference for beans stored in the

aerated bin and in the controlled chamber were described, respectively, as "good", "soft" and "liked" while beans stored in not aerated bin and in bags in warehouse were rated a "slightly good", "slightly soft", "liked slightly".

Darkening of the seed coat was observed in all the treatments but it was more pronounced for the beans stored in bags in warehouse.

The chemical components evaluated showed no significative change during storage, exception being made for reducing sugars in which a significant decrease was detected.

There was no significant increase in the PDI up to 8 months, however a significant increase was observed after 12 months storage.

Free fatty acids did not increase during the storage time in the beans kept in the controlled chamber. In the three other treatments it increased during the storage time in the following order:
1) not aerated bin; 2) bags in warehouse and, 3) aerated bin. After 12 months storage the F.F.A. value was 46.5% lower in the aerated bin as compared to the not aerated one.

The percentage of broken grains during handling of the product in bulk was 8.3 to 9.0%, including 4% breakage during the drying process.

INFLUENCE OF STORAGE AND OF DIFFERENT SOAKING AND COOKING TREATMENTS ON THE QUALITY OF CANNED DRY BEANS (Phaseolus vulgaris, L.)

Mariza Hoelz Jackix
M.S. Thesis, FEAA, UNICAMP
Campinas, SP, 1978

SUMMARY

The main purpose of this work was to test the effect of soaking and cooking periods on different varieties of canned by beans (Phaseolus vulgaris, L.)

Studies were carried out using "Rosinha", "Carioca", "Rico 23" (black beans), "Bico de Ouro" and "Piratã" beans obtained during wet and dry seasons.

Tests were performed soon after harvest and 12 and 18 months of storage respectively.

Soaking processes were as follows:

- water at 25°C for 8 hours;
- 0,5% SHMP (sodium hexametaphosphate) solution at 25°C for 8 hours;
- water at 25°C for 3 hours, after scalding;
- water at 60°C for 1 hour;
- 0,5% SHMP solution at 60°C for 1 hour.

Cooking periods were:

- 20 minutes at 121°C;
- 30 minutes at 121°C;
- 40 minutes at 121°C.

The protein content was significantly higher for dry season beans, specialy for the "Bico de Ouro" and "Rico 23" beans.

Water absorption through soaking was not increased when using 0,5% SHMP solution; however cooked beans where significantly more tender, showed a greater weight grain when SHMP was used independent of the stage of the process at which the above salt was added.

For assessing the tenderness of the product, sensory analyses and Instron tests were carried out.

A relation between organoleptic and mechanical test was obtained when in addition to the measurement of the force applied in the Instron the variation coeficient of force was considered.

The beans were classified as tender by testing panel when the medium force applied in the Instron was less than 1200gf and the variation coeficient less than 32%.

Beans after 1 year storage did not become tender even after 40 minutes of cooking, when water only was used for soaking and cooking.

The use of 0.5% sodium hexametaphosphate solution as filling liquid, dispensed with necessity of soaking and made possible to obtain

after 30 minutes of cooking a product considered "ideally" tender by the testing panel.

SENSORIAL - STATISTIC METHODOLOGY FOR EVALUATION OF FLAVOR AND TEXTURE OF STORED DRY BEANS (*Phaseolus vulgaris*, L.)

Ruth dos Santos Garruti, Dr.
"Livre Docência" Thesis, FEAA/UNICAMP
Campinas, SP, 1981

SUMMARY

The material used in the present work consisted in the treatment of the cultivars Carioca, Aroana and Rosinha G-2 obtained from Tietê, Mococa and Campinas, representing common beans planted and harvested during the dry and wet seasons of the years 1978, 79 and 80, which after cleaning were stored at the temperature 24 - 26°C and relative humidity of 65 - 70% during 6 months, and e exceptionally during 14 months in the case of beans of the dry season 1979.

There were carried out sensory analyses to assess flavour and textures, and physical and instrumental analysis to obtain an objective texture measurement of stored beans.

Physical analysis consisted in the determination of the percentage of hard-shell beans and of the cookability of total grains, the latter determination being effected in an experimental cooker for 25 grains, constructed specially for this purpose. The instrument showed good reproducibility of the results for the same treatment beside a good correlation with the measurement of sensory and instrumental texture parameters.

The results of the above analysis were submitted to an univariated analysis of variance (ANOVA) and the Tukey test to compare the media. For instrumental texture measurements standard deviations and variation coeficients were calculated.

Advanced statistical techniques were applied: multivariated analysis of varience (MANOVA) for sensory measurements of bean flavour and Principal Component Analysis (PCA) for sensory texture measurements of hardness cheweness parameters. These techniques were used for first time for the products studied.

The sensory statistical method developed for flavour assessment and consisting in MANOVA application to the results of quantitative descriptive analysis (QDA) obtained by trained testing panel, proved to be a good tool for assessing the flavour of common beans stored for 6 - 14 months. Owing to favourable experimental conditions the beans did not suffer deterioration, the off-flavour descriptors were not conspicuous and therefore were not included in the MANOVA since the results did not follow a normal distribution as confirmed by exploratory analysis of stem and leaf.

Of the 9 descriptors selected for descriptive analysis only natural flavour and "overall impression" characterized the bean flavour.

The sensory-statistical method developed for the texture avaliation, which consisted in the application of the principal component analysis (PCA) to the results of the sensory texture profile analysis (STPA) obtained by trained tasting panel also proved to be an efficient tool for assessing the texture quality of common beans.

Statistical correlation analysis was applied to the results of the following texture parameters: cookability and hard-shell; hardness and cheweness; shell and mesocarp hardness.

The results of physical analysis showed:

a) The cookability time varied between the initial phase and after 6 months storage for the beans of dry season but not for those of the wet season. There was a significant difference at 5% level between the dry and wet season of 1978, in flavour of the dry season, but only in the initial phase, indicating the disapparence of the cookability time differences after 6 months storage.

b) The hard-shell beans percentage was higher in the dry season of 1978 but in 1979 it was higher in the wet season with a significant difference at 5% level 6 months storage producing a much higher hard-shell beans percentage (37.55) than the initial phase (9.33), indicating that the ocurence of hard-shell beans increased with storage more consistently during the wet season. No significant differences in relation to flavour, were observed between the cultivars and different applications of fertilizer nitrogen, in the initial phase, but the beans from Tietê showed in general better natural flavour characteristics than from Mococa at a significance level of 5%, and to a lesser degree than from Campinas. After 6 months storage this difference disappeared. The comparison between the dry and wet season showed that the beans of the latter displayed a better flavour.

In relation to the texture (sensory) the Carioca cultivar produced consistently better results differing from Aroana and Rosinha G-2. They

agreed with the rheological texture measurements obtained with the Instron Universal Machine, while the beans from Tietê and Campinas showed better texture than those from Mococa.

The contrast between the initial and final storage phases was significant at 5% level for the sensory as well as for rheological measurements, indicating that the storage increased the hardness of shell and endocarp, while the dry season beans showed better texture than those from wet season.

STORAGE OF DRY BEANS IN BURLAP BAGS AND PAPER BAGS LINED WITH POLYETHYLENE UNDER DIFFERENT STORAGE CONDITONS

SANTOS, L.A. PROJECT LIDER

Agreement. ITAL/EMBRAPA - Not published report, 1981.

Dry beans var. Carioca with 12,2% moisture content were stored during 12 months in burlap bags and in kraft paper bags lined with polyethylene in controlled chambers at 20ºC and 70% R.H. and at 30ºC and 70% R.H..Samples were taken at 3 month intervals and submited to the following tests: moisture content, germination, accellerated aging, cooking time, hydration rate, available methionine and sensory evaluation.

It was observed that storage temperature had a remarkable effect in the above mentioned parameters. Differences between samples packaged in burlap bags and in kraft paper bags lined with polyethylene stored under the same conditions, were not significant at the 5% level.

Cooking time changed from 44.5 to 53.6 min at 20ºC and from 44.5 to 92.1 min at 30ºC during the first 9 months of storage.

Kramer shear press values for cooked beans changed from 1.75 lbf/g to an average de 1.80 lbf/g after 6 months storage at 20ºC and 70% R.H.; when stored at 30ºC and 70% R.H. values changed from 1.75 lbf/g to 1.98 lbf/g.

Sensory evaluation of the attributes appearance, flavor, texture and overall preference using a 7 - point (where 7 = very good) hedonic scale for beans stored at 20ºC and 70% R.H. during 12 months changed from average values of respectively, 5,7; 5,6; 5,0 and 5,4 to 5,2; 4,4; 3,6 and 4,1; at 30ºC and 70% R.H. the initial valves of 5,7; 5,6; 5,0 and 5,4 changed, during the same storage period to 3,75; 3,0; 2,0; 2,65 and 3,1, respectively.

TECHNOLOGICAL QUALITY OF DRY BEANS (PHASEOLUS VULGARIS L.) STORED UNDER NITROGEN

Maria Regina SARTORI

Ph.D. Dissertation. Department of Grain Science & Industry - Kansas State University, Manhattan, KS, USA, 1982.

Pinto beans with 14.7% initial content were stored at 75ºF-75% R.H. under forced air (10 cc/min), forced nitrogen (10 cc/min) and cotton bags during 6 monthd. Both air and nitrogen had the R.H. adjusted to 75% before being forced through the beans. Quality changes during storage were evaluated by moisture content, cooking time, texture, fat acidity, color and flavor tests.

Within storage periods (2, 4 and 6 months) Pinto beans stored under forced nitrogen did not differ significantly from those beans stored under forced air or in cotton bags as far as cooking time, texture, fat acidity and flavor were concerned. Significant differences in relation to the initial values were registered over time in storage for cooking time (after 2 months), texture (after 4 months), and fat acidity (after 6 months). Raw/vegetable scores tended to decrease and beany scores tended to increase over time for all treatments.

Both raw/vegetable and beany flavor scores tended to indicate a reduction in Pinto bean flavor quality over time and a slight tendency for beans stored under nitrogen to retain raw/vegetable flavor and to develop less beany flavor. Pinto beans stored in nitrogen kept the light colored seed coat, characteristic of newly harvested beans, during the entire storage period. A significant darkening was detected in beans stored in air after only 2 months.

METHODOLOGY USED BY BRAZILIAN RESEARCHES FOR THE EVALUATION OF TECHNOLOGICAL QUALITY OF DRY BEANS

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ITAL

METHODOLOGY

There is some variation in the methodology used by Brazilian researchers for the evaluation of technological quality of dry beans.

Cooking Test

GARRUTI (1981) soaks beans in distilled water at ambient temperature during 6 hours. The cooking test is than performed by placing 25 seems in a Modified Mattson Cooker, type Jab-77 (V. Fig. 1) with a 90g rod resting on each one and placing the apparatus in boiling distilled water (96 - 97°C, in Campinas). Start of cooking time is considered the moment the water restarts boiling. End of cooking time is considered when the 139 rod penetrates the bean.

SILVA CAMPOS (V. SANTOS et alii, 1981) also uses a Modified Mattson Cooker, type Jab-77 for the evaluation of cooking time, in the same way described by GARRUTI (1981), but using tap water. Samples are prepared by soaking the beans in tap water, at room temperature, during 12 - 16 hours.

SARTORI (1982) uses a Modified Mattson Cooker, as described by JACKSON (1979). In this model the 100 rod capacity device of Mattson and Burr was scaled down to hold a 25 bean sample and fit into a 2 liter beaker for convenience (V. Fig. 2 and 3). To prevent seed displacement during cooking due to the pressure exerted by boiling water, SARTORI (1982) covered the bottom plate with coarse wire mesh. This modification solved the problem

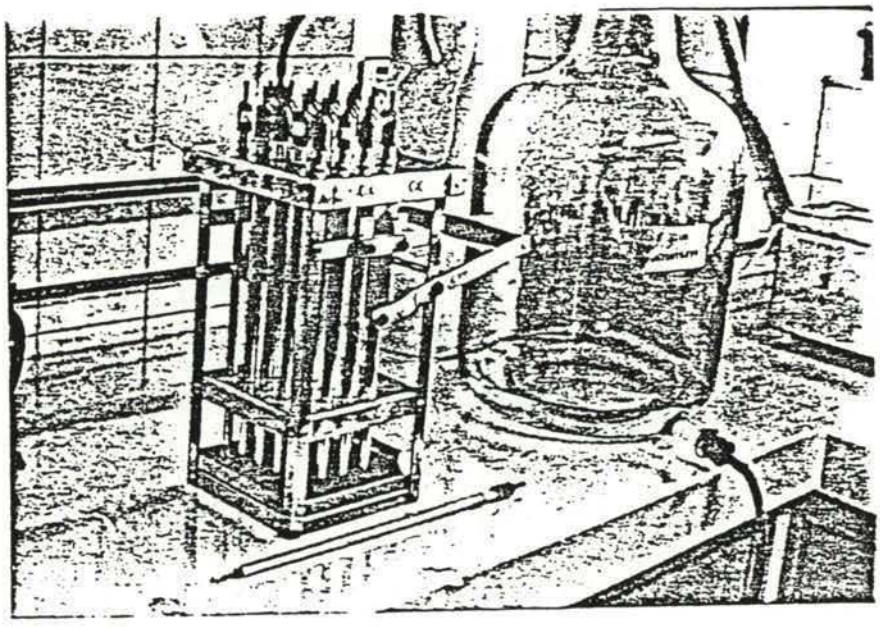

FIGURE 1. Modified Mattson Cooker, type Jab-77, built at ITAL.

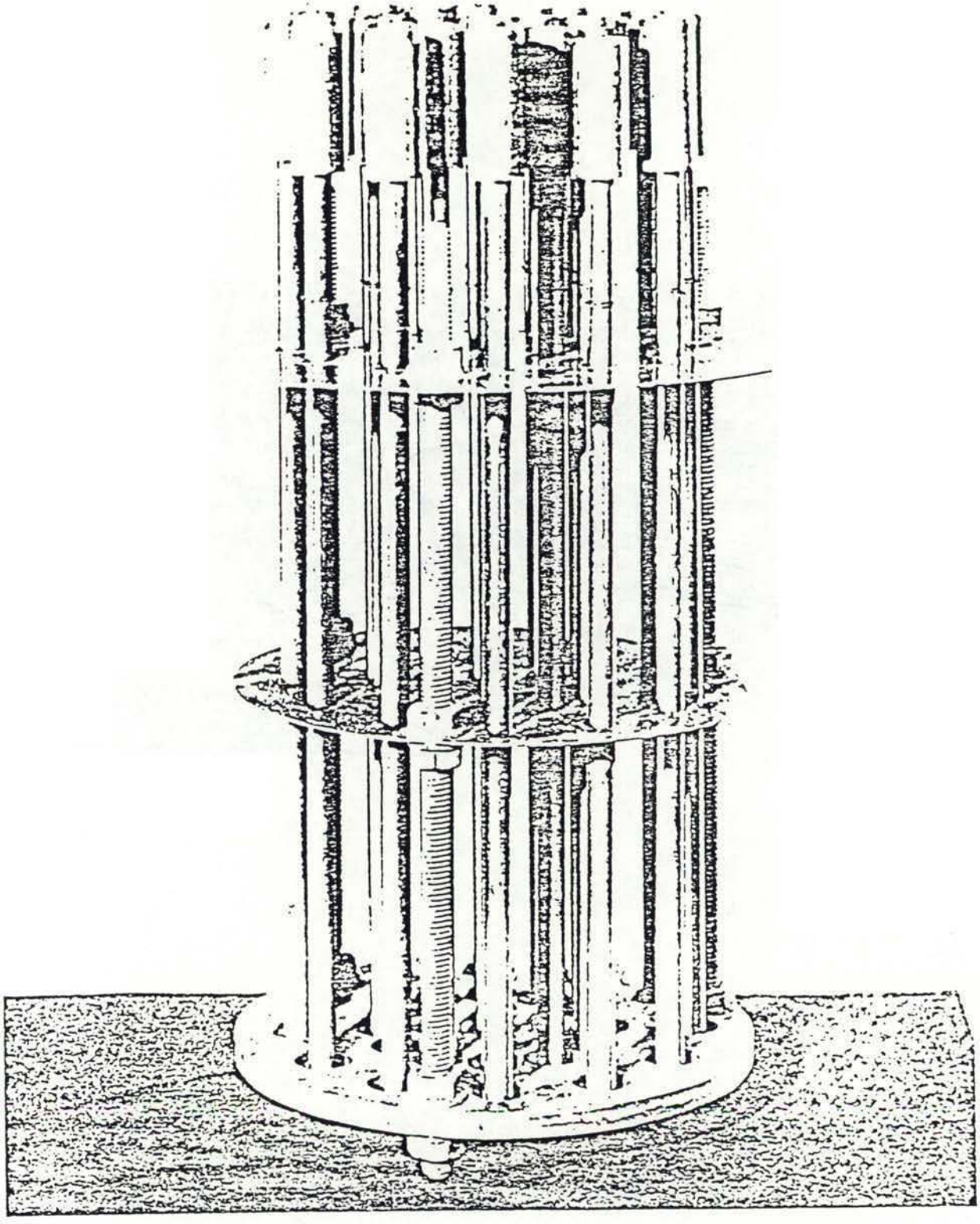

FIGURE 2. Mattson cooker as modified by Jackson (1979).

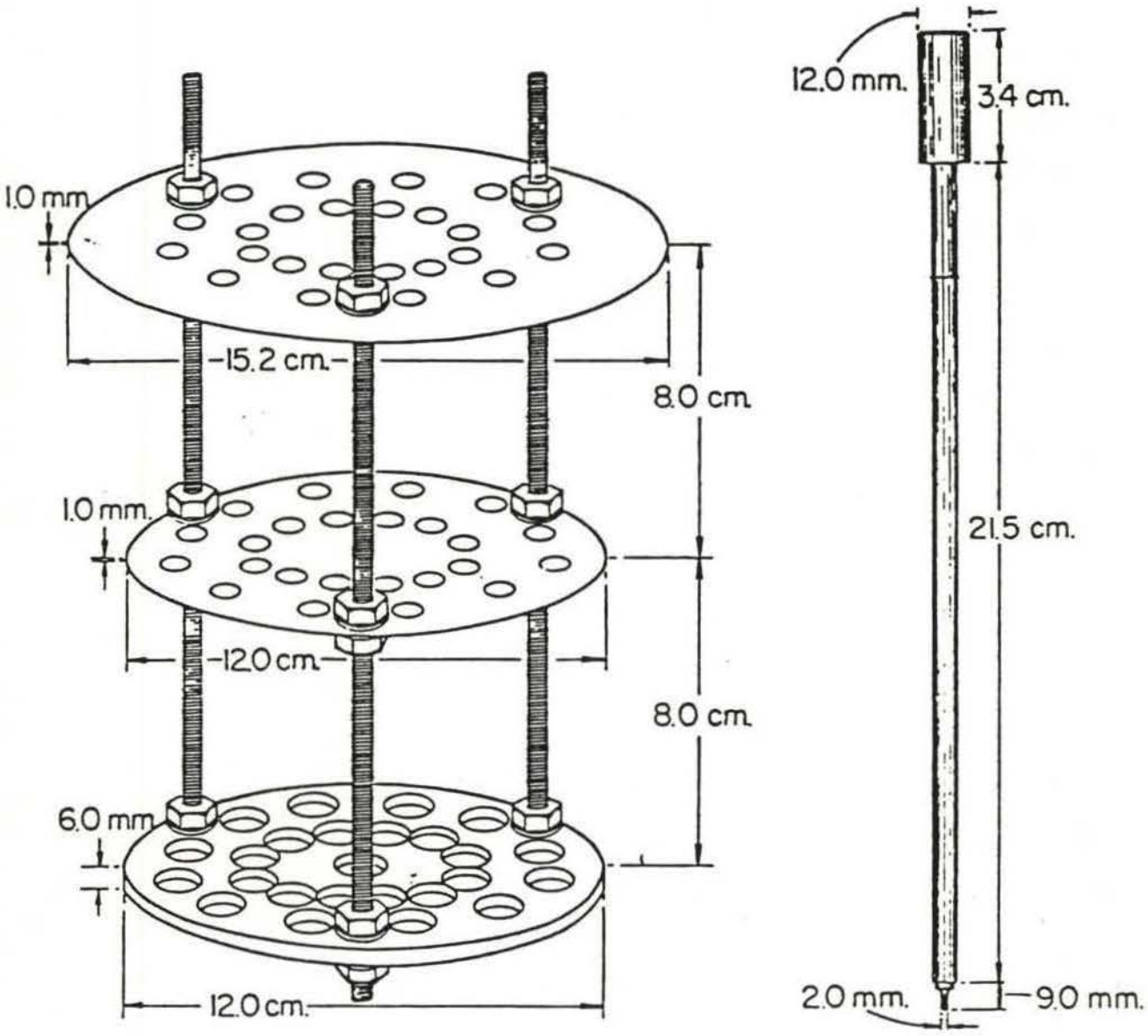

FIGURE 3. Dimension for rack and plungers of the Modified Mattson Cooker. Holes to acomadate plunger tip are at the bottom of each depression (not shown). Source: JACKSON, 1979.

of seed displacement and was used throughout her study. The weight of the rod in this apparatus was 82.00 gram. Copies of it have been made in Brazil, using a 90.00 gram rod and making additional holes in the bottom plate to solve the problem of seed displacement. SARTORI (1985) has also used the modified Jackson Cooker, type Jab-77. Samples are soaked in destilled (1982) or deionised (1985) water at room temperature during 12 - 16 hours. The 25 beans for the cooking test are selected from the soaked sample, discarding beans with ruptured or absent seed coat. Start of cooking time is considered when the apparatus touches the boiling deionized water. End of cooking time is considered when the 13º rod penetrates the bean against which is had been resting.

Texture

GARRUTI (1981) evaluates dry beans texture by using a puncture test with a Instron Universal Testing Machine - Model 1132, using 50 individual beans. The force - distance curve during the penetration of each bean is registered by a chart recorder. The full load scale is 5kg. The head speed is 10cm/min and the chart speed 4cm/min. The diameter of the cell (needle) used in the puncture tests 1/16" (1,6mm). The needle was adapted to the head and this one regulated in such a way that the needle would automatically penetrate only 0.5cm and immediately withdrawn from it (Fig. 4). The maximum forces (kg) and the depths (d) where the maximum forces ocurred (cm) were determined by force-distance curves, as shown in Fig. 5.

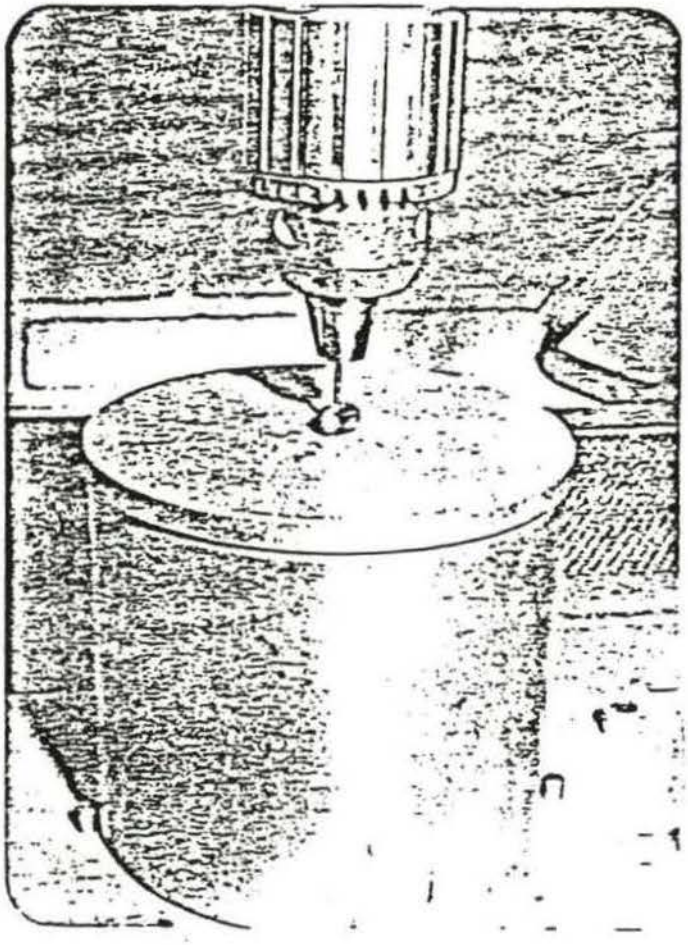

FIGURE 4. Puncture test using the Instron Universal with a needle (flat end) 0.16cm in diameter and an aluminum block 11,75cm in diameter.
Source: GARRUTI (1981).

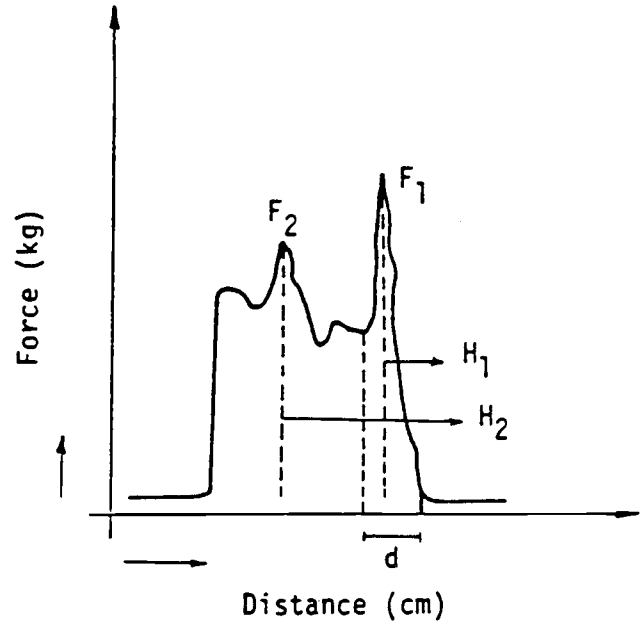

FIGURE 5. Typical force-distance curve (kg-cm) produced by the puncture test using the Instron.
Source: GARRUTI (1981).

She considers:

H_1 = Measure of the force (F_1) necessary to break the seed coat;

H_2 = Measure of force (F_2) necessary to pull the needle from the bean.

SILVA CAMPOS (V. SANTOS et alii, 1981) evaluates texture using a Kramer Shear Press, model TP-1 standard shear compression cell (model CS-1 - Food Technology Corporation), 3000 lb ring, down stroke speed of 20cm/min, using 50g samples of cooked beans. Samples are prepared by soaking 200g beans in about 1000ml tap water at ambient temperature during 12 - 16 hours, cooking using 600ml tap water in a domestic pressure cooker during 25 minutes, cooling and draining the beans during 2 minutes using a 8 mesh screen. The value of the forces are obtained by measuring the heighest peak obtained in the force x distance curves registered by a chart recorder (V. Fig. 6).

SARTORI (1982, 1985) also utilizes the Kramer Shear Press with a standard shear compression cell and a 3000 lb ring for texture evaluation. However she uses 50g (dry weight basis) samples and distilled (SARTORI, 1982) and deionized (SARTORI, 1985) water. Samples are 50 soak at room temperature, in deionized water, during 12 - 16 hours, drained, quickly rinsed with 200ml deionized water and cooked 20 (SARTORI, 1982) or 25 minutes (SARTORI, 1985) in 1000ml beakers, starting with boiling deionized water. After cooking the beans are cooled by imersing the beakers with the beans in cold water. Texture measurements are made approx. 1/2 hour after cooking.

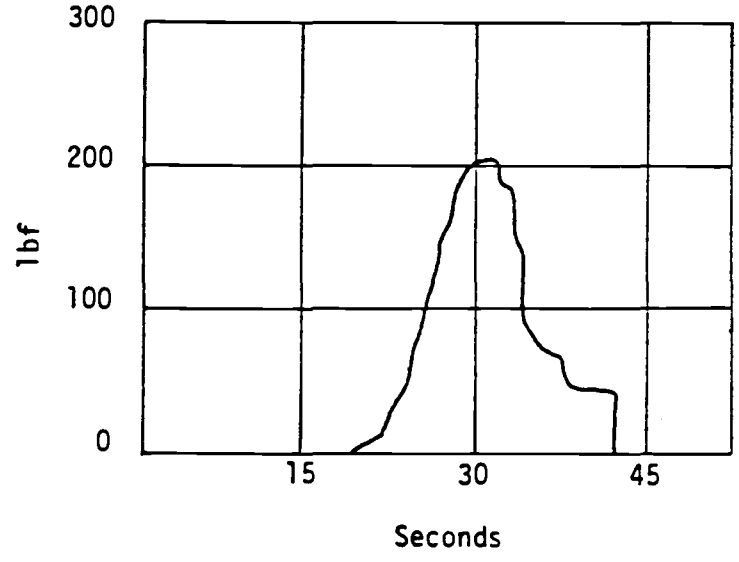

FIGURE 6. Typical force-distance curve of cooked black beans using the Kramer Shear-Press.
Source: QUAST & SILVA (1977).

Sensorial Tests

GARRUTI (1981) for the sensorial tests used for each sample 8g of beans, soaked during 6 hours in 50ml beckers, codified in a number sufficient to serve 7 panelists.

The panelists receive the samples (following the randomization of the incomplete block design) in termic trays kept at 45°C. Panelists were instructed to always take to the mouth the same number of beans equal to 5, for each sample, and register the impression in appropriate sheets (V. Fig. 7). The method is quantitative descriptive, and to each attribute of natural flavor or off-flavor corresponds one sample represented by a 9cm line, anchored at the left and right extremities by the words week and strong, respectively.

The panelists makes a small vertical line in a point of the horizontal line that better describes the intensity perceived of each descriptive term of flavor.

The method besides giving the flavor profile identifying the descriptive terms by the order in which they are detected, it identifies the perceived intensities.

Based on the results the configuration of the quantitative descriptive analysis can be drawn. It is formed by radial lines starting in a central zero point. Each line represents a descriptive term and the available intensity for each descriptive term (the center represents zero

Name _____ Date _____

Sample nº _____

Instructions: Please, make a vertical line in the horizontal line in a point that better describes de flavor.

Flavor:

Natural:

	Weak	Strong
Cooked beans	_____	
Uncooked beans	_____	

Off-Flavor:

Bitter	_____
Chemical	_____
Burned	_____
Sour	_____
Insect	_____
After taste	_____
Overall impression	_____

FIGURE 7. Score card used to register the answer of the panelists in the Quantitative Descriptive Analysis to describe the flavor of dry beans.

point. Each line represents a descriptive term and the available intensity for each descriptive term (the center represents zero intensity and the extreme point intensity 9) : by connecting the average intensities for all the descriptive terms we have the flavor profile of the dry bean sample (V. Fig. 8).

MIYA (V. JORDÃO et alii, 1976) for the sensorial test used for each sample 200g of beans soaked overnight and cooked during 15 minutes in a domestic pressure cooker using 1000ml distilled water. Samples were presented to the panelists in white dishes. For the evaluation she used a 10 point scale where for flavor 10 = very good; 1 = very bad; for texture 10 = very soft; 1 = very coarse and for preference 10 = liked very much; 1 = disliked very much.

SARTORI (1982) while doing the preliminary work for her dissertation, at the Department of Grain Science, Kansas State University, noticed that American Panelists would consistently prefer "old beans" to "new beans" in opposition to the Brazilians preference. Evaluation procedure was than developed by a flavor specialist from the Department of Foods and Nutrition, Kansas State University, who, along with two trained individuals, identified "raw vegetable" and "beany" flavors and "beany" flavors and "bitter" taste in newly harvested and aged Pinto beans. This standardization panel rated the control sample (Pinto beans with approx. 12% moisture content kept at 42°F since harvesting) and aged sample (Pinto beans with moisture content adjusted to approx. 15% were "aged" in an incubator at 45°C for 30 days). Beans previously rated for "raw-vegetable".

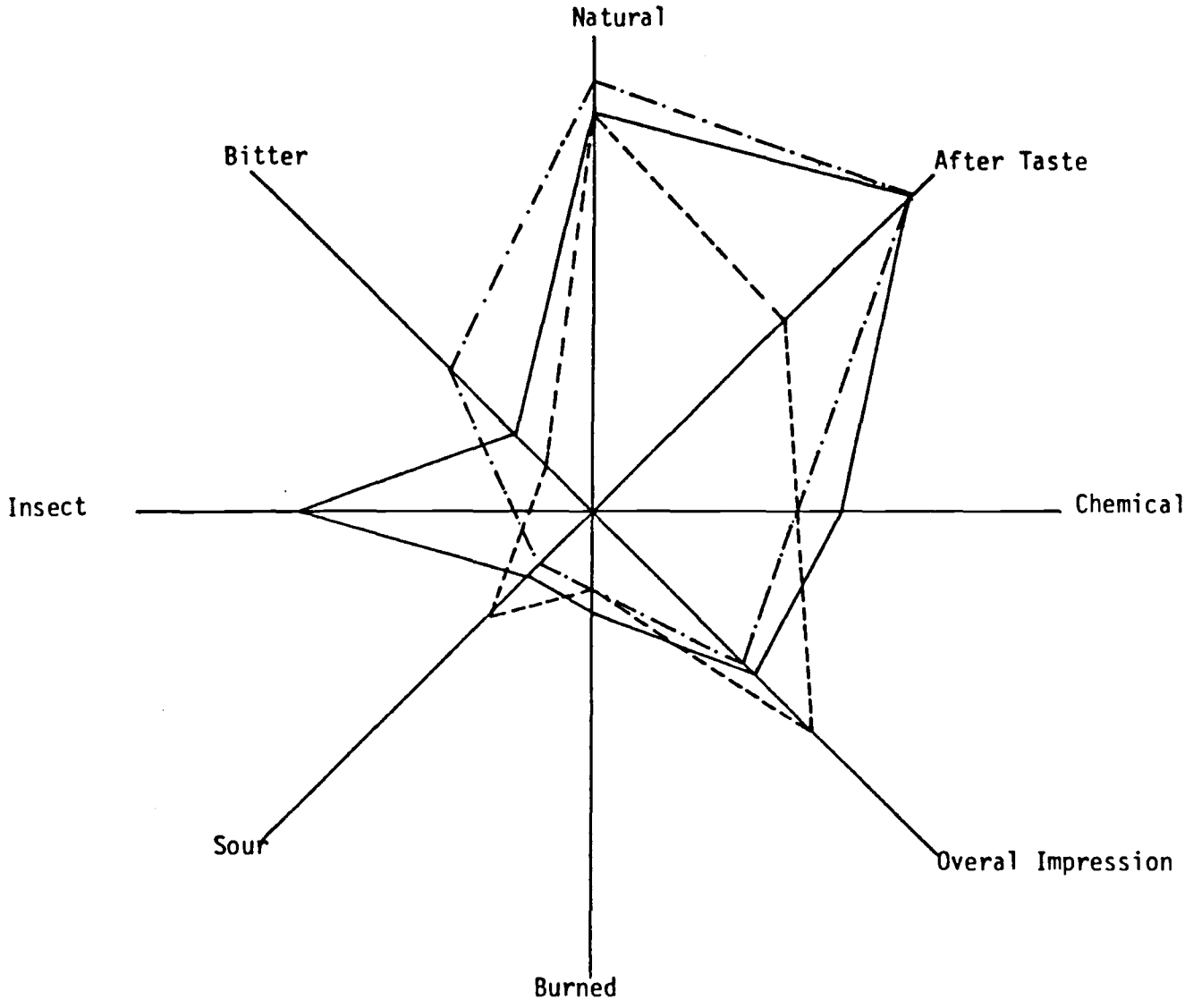

FIGURE 8. Configuration of the Quantitative Description Analysis (Q.D.A.) of flavour of dry bean var. Carioca, N_{40} - wet season 79, after 6 months storage.

Source: GARRUTI, R.S. 1981.

"beany" and "bitter" were used for training regular panelists, who were asked to compare and adjust their own ratings to those of the standardization panel (Fig. 9). The rated control was subsequently included in all the flavor evaluation sessions throughout the experiment to serve as a point of reference. Individual ratings, marked on the score card by placing vertical lines on 6 1/2" horizontal lines running from "none" in the extreme left to "a lot" in the extreme right (Fig. 10), were measured by a ruler and distances used in the statical analysis.

Samples for the test were prepared by soaking 150g of beans in 500ml of distilled water for 12 - 16 hours at room temperature. The samples were then drained, quickly rinsed with 500ml distilled water and cooked, starting with 500ml boiling distilled water. To ensure that the cooked beans would have nearly the same texture, the cooking time used for each treatment was the average time obtained with the Modified Mattson Cooker. No adjustments were made for possible differences in cooking time due to changes in atmospheric pressure.

The "raw-vegetable" and "beany" flavors were evaluated in warm samples and the "bitter" taste in cold samples. Evaluations were carried out within 1 hour after cooking.

NAME: _____ DATE: _____

DESCRIPTIVE ANALYSIS WITH SCALING - TRAINING SESSION

Objective of today's meeting: To get acquainted with the flavors

RAW/VEGETABLE

BEANY

and the taste

BITTER

Additional task for panelists participating for the second time in the training sessions: rate the unknown sample in relation to the others.

Raw/Vegetable (hot)

NONE #3 #1 A LOT

BEANY (hot)

NONE #1 #3 A LOT

BITTER

NONE #3 #1 A LOT

COMMENTS:

FIGURE 9. Score-card used the training regular panelists, samples ≠ 1 and ≠ 3 were rated by the standardization panel.

NAME: _____ DATE: _____

Please evaluate the flavors RAW/VEGETABLE and BEANY and the taste BITTER of the given samples, as compared to sample #1 (check).

Make a vertical line on the horizontal lines to indicate your rating of each sample. Label each vertical line with the code number of the sample it represents.

RAW/VEGETABLE

NONE #1 A LOT

BEANY

NONE #1 A LOT

BITTER (evaluate #1 also)

NONE A LOT

Comments:

FIGURE 10. Score card used to register the answer of the panelists in the Quantitative Descriptive Analysis to describe the flavor of dry bean. Source: SARTORI (1982).

Viscosity

In Brazil dry beans are mainly consumed cooked in water, to which spices are added at the end of the cooking process. The final results is a dish in which there are mainly whole beans in a broth that can be more or less thick, depending on the quality of the beans used. It is known that "old beans" produce a less consistent broth which is an undesirable characteristic from the Brazilian consumer point of view. The Evaluation and Quality Control Section of ITAL has just started a study on the correlation between the viscosity of cooked bean broth, as evaluated by a Brookfield viscosimeter, and the total solids content of it. Depending on the results of this study the measurement of the viscosity of the bean broth will be used as an index of quality.

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CONSERVATION OF TECHNOLOGICAL QUALITY OF BEANS DURING STORAGE

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INTRODUCTION

From the beginning of the development of the embryo in the mother- plant to the moment of processing or final consumption, genetic and envrionmental factors interact, modifying the quality of oleaginous seeds and legumes, affecting their commercial value and their acceptability to the consumer.

During storage, gradual, irreversible and cumulative deterioration takes place. Its speed depends upon the storage environment, the product itself and its condition when originally stored.

The deterioration of the technological quality of beans while stored in an open-air environment is characterized by the increased time needed for cooking, increased hardness (especially of the integument), changes in flavor and darkening of the tegument. These changes are accelerated by storage under conditions of high temperature and high relative humidity. Drying of the moisture content until it equals the 65% to 70% relative humidity and storage temperatures of 20°C or less have produced satisfactory results for storage of up to twelve months (DEL GIUDICE, et. al., 1972; JORDÃO et. al., 1972; GAULLIEZ, et. al., 1979; SANTOS et. al., 1981).

Hardshell and Hard-to-Cook

Despite the fact that these two terms are frequently used as synonyms, they refer to two distinct phenomena: "Hardshell" is a condition found in mature, dry legumes, which keeps them from absorbing water for a reasonably long period when they are soaked (BOURNE, 1967); "hard-to-cook" describes a condition in which they require prolonged cooking to soften or in which they do not soften despite long cooking in boiling water.

GLOYER (1921) indicates that there are two types of hardness to be found in beans: hardness of the cotyledons, called sclerema, and hardness of the tegument, called hardshell. According to this author, sclerema could be caused by storage in humid, hot environments and hardshell might be caused by storage of beans under conditions of artificial heating and low relative humidity, as well as by bean maturation during hot, dry periods. The occurrence of hardshell beans might also be controlled by hereditary factors. Thus, it would be possible to develop, by means of genetic improvement, lines of beans that would not exhibit the hardshell phenomenon, even in environmental conditions favoring its development (LEBEDEFF, 1943).

The process of cooking samples of previously hydrated beans which contain a certain quantity of hardshell until the hardshell are edible may require such a long cooking time that the rest of the beans disintegrate (MORRIS, et. al, 1950). Thus, hardshell beans are also hard-to-cook.

Legumes which present the hardshell phenomenon tend to have a moisture content in equilibrium with the lowest relative humidity to which they have been exposed (HYDE, 1954).

Cooking Time

The cooking time of food legumes is considered to be the period necessary for the product to reach a degree of softness acceptable to the consumer.

In stored beans with a moisture content equal to or less than 10%, temperature and storage time have little or no influence on product quality. Beans with a moisture content of less than 10% stored at 25°C for two years maintain their quality almost as well as those with less than 10% moisture stored at -23.3°C (MORRIS AND WOOD, 1956).

In stored beans with a moisture content of more than 10%, cooking time increases with the storage period, degree of humidity and temperature.

With approximately a 12% moisture content (65%-70% relative humidity), stored at temperatures of 20°C or less, beans may be satisfactorily preserved for up to twelve months (DEL GIUDICE, et. al., 1972; JORDÃO, et. al., 1976, GAULLIEZ, et. al., 1979; SANTOS, et. al., 1981).

In the Carioca variety bean, with an average 12.2% moisture content, stored at 20°C and 70% relative humidity, cooking time increased, on the

average, from 44.5 to 56.5 minutes for nine months of storage. For the same storage period, at more than 30°C and 70% relative humidity, cooking time increased from 44.5 to 97.3 minutes (SANTOS, et. al., 1981).

In soybeans stored at 14°C and 75% relative humidity, cooking time in a pressure cooker at 15 lb/in^2 increased from 20 to 25 minutes for twelve months of storage. For the same storage period, at 30°C and 75% relative humidity, cooking time increased from 20 to 50 minutes (SARTORI and ARCKOLL, 1976).

Generally, it has been shown that temperatures of 24°C or more and relative humidity of more than 70% are unfavorable for the storage of beans for more than six months.

Varieties of beans produced in the same place, at the same time and under the same conditions showed differences in cooking time after being harvested and stored at 25°C and 70% relative humidity. Generally significant increases appeared after six months of storage (TABLE 1).

Pinto beans, very similar to the Carioca variety, with an initial moisture content of 14.7%, stored at 25°C with 75% relative humidity, showed increased cooking times, from 24.5 to 45.4 minutes, after six months of storage (SARTORI, 1982). The same type of beans, with 14.4% moisture content, stored at 32.2°C, showed an increase in cooking time from 24 to 340 minutes, after seven months of storage (BURR, et. al., a968).

TABLE 1. Cooking Times of Different Varieties of Beans Stored at 25°C and 70% Relative Humidity for Different Time Periods

Variety	Storage Period (months)				
	0	3	6	9	12
Aroana-80	36.6	38.8	57.0	60.2	75.0
Aysõ	40.8	41.7	59.7	72.4	73.8
Carioca	29.0	30.6	44.0	52.9	57.9
Carioca-80	40.6	41.0	63.7	66.0	75.9
Catu	27.4	31.0	35.6	40.8	42.7
Rosinha G-2	20.1	26.6	38.0	68.9	67.7

Source: SARTORI, et. al.,1985.

Texture

As with cooking time, the hardness of food legumes cooked for a specific period tends to increase according to the storage period, relative humidity and temperature (NORDSTROM and SISTRUNK, 1979; SARTORI and ARKELL, 1976; JORDÃO et al., 1976; SEFA-DEDEH, et al., 1979; JACKSON, 1979, SANTOS, et al., 1981; ATUNES and SGARBIERI, 1979; SARTORI, 1982).

In the Carioca variety, with an average moisture content of 12.2%, the values obtained in the Kramer Shear Press, after 20 minutes of cooking in a pressure cooker, increased from 1.75 lb/g to 1.80 lb/g after six months of storage at 20°C and 70% relative humidity, For the same storage period, at 30°C and 70% relative humidity, the values obtained increased from 1.75 lb/g to 198 lb/g (SANTOS, et. al., 1981).

Bean varieties produced in the same place, at the same time and under the same conditions, harvested and stored at 25°C and 70% relative humidity presented differences after 25 minutes of cooking in an open kettle. Likewise, the required cooking time and significant increases in the degree of hardness were generally observed after six months of storage (TABLE 2).

MORRIS and WOOD (1956) also observed that in beans with a 13-15% moisture content, for the group, there was a significant deterioration in texture after six months of storage at 25°C.

TABLE 2. Softness (lbf/g of dry weight) of Different Varieties of Bean Stored at 25°C and 70% Relative Humidity for Diverse Periods of Time, in Values Obtained in the Kramer Shear Press.

Variety	Storage Period (months)				
	0	3	6	9	12
Aroana-80	10.0	10.5	12.5	14.2	14.6
Aysó	9.4	10.9	12.7	14.9	15.5
Carioca	7.6	8.1	9.2	11.7	14.9
Carioca-80	10.1	10.8	14,7	15.1	16.1
Catu	9.1	9.6	11.9	14.2	14.8
Rosinha G-2	7.2	7.8	11.2	11.6	12.3

SOURCE: Sartori, et.al., 1985

The hardness of pinto beans with an initial moisture content of 14.7% as measured by the Kramer Shear Press increased from 2.12 to an average of 2.86 lb/g of dry weight after six months of storage at 24°C and 75% relative humidity (SARTORI, 1982).

Soybeans were shown to be equally sensitive to temperature. Their degree of hardness after twelve months at 14°C and 75% relative humidity was 1.24 lb/in^2; at 30°C and 75% relative humidity, it was 2.95 lb/in^2 (SARTORI and ARKOLL, 1976).

In fresh, uncooked beans, the loss of cooking quality may or may not be related to an increase of hardness. Black beans rapidly aged by storage at 41°C and 100% relative humidity during 7 to 14 days showed a significant increase in cooking time compared to recently-harvested beans (FIGURE 1). Nevertheless, recently-harvested uncooked beans or beans aged for two weeks required the same pressure to mash, although the beans aged for seven days requires less pressure than the recently-harvested beans (Table 3).

As can be seen in Table 3, the legumes stored for 55 days at 41°C and 75% relative humidity required significantly higher pressure to be mashed than any of the other samples. In this case, it may be concluded that the storage conditions caused a physical hardening of uncooked beans. Apparently, however, the correlation between the hardening of uncooked beans and

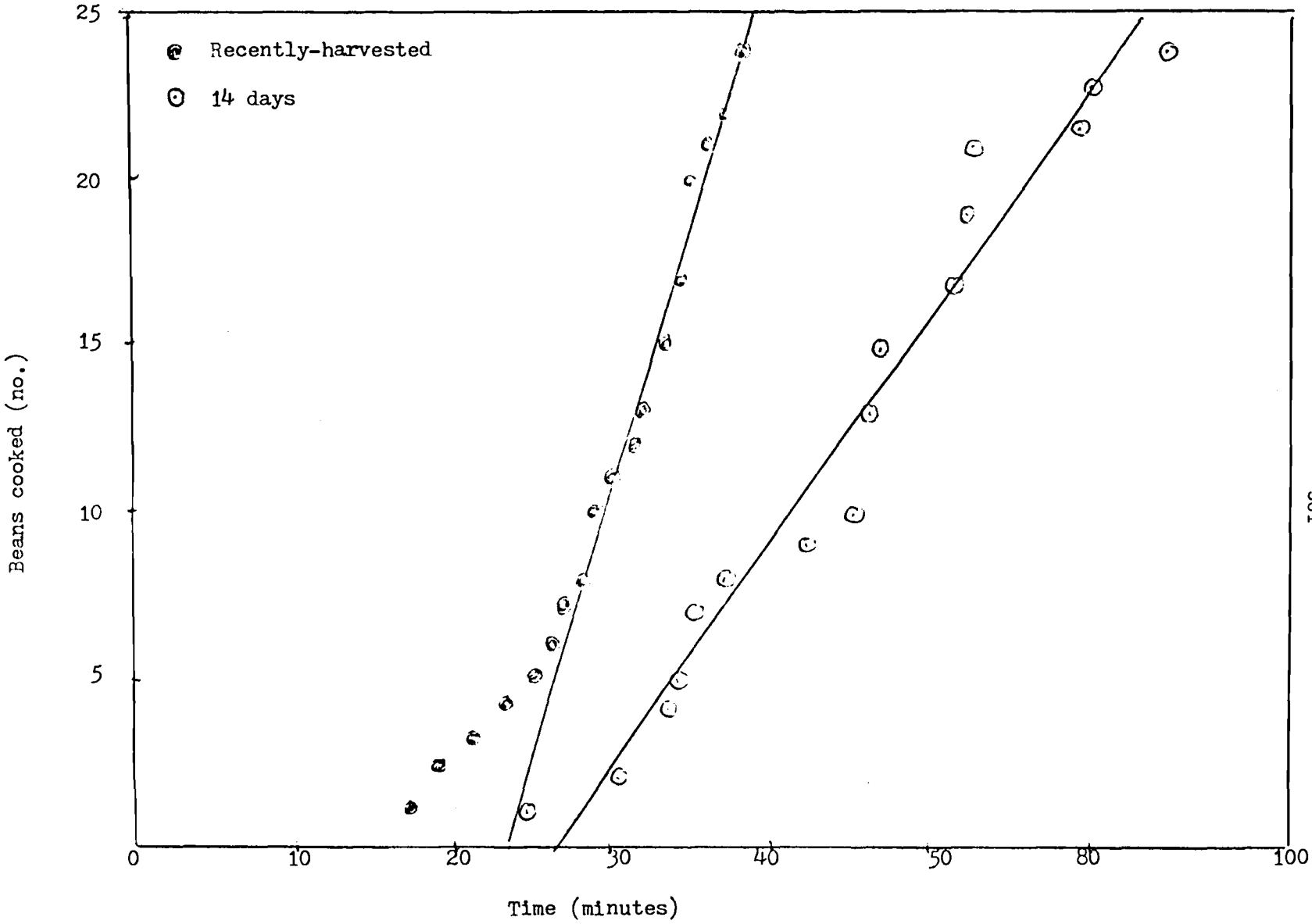

Figure 1. Graph of the number of cooked beans as a function of time for samples of black beans recently-harvested and artificially aged for 14 days at 41°C and 100% relative humidity

TABLE 3 Hardness of recently-harvested black beans and aged black beans, as determined by the Kramer Shear Press.

Storage period at 41°C (days)	Relative humidity during storage (%)	With integument intact	Only integument	Only cotyledons
0	–	74.3	24.2	50.1
7	100	60.1	10.3	49.8
14	100	70.2	25.5	44.7
55	75	101.9	41.5	60.4

DMS 4.0 at 1% probability level

SOURCE: Jackson (1979)

their cooking quality holds true only with respect to samples stored for long periods of time. The hardness values for uncooked beans did not correlate with the cooking quality for beans stored for other periods at 41°C and 100% relative humidity (JACKSON, 1979). These observations suggest that the increased cooking times actually precede an increase in the hardness of uncooked beans. They also suggest chemical transformations probably involving chelating agents must precede any lignin process during storage (SARTORI, 1982).

Possible Explanations of Loss of Cooking Quality and Hardening of Food Legumes during Storage

The expression"cooking quality", as applied to food legumes, refers to the time needed for them to attain a degree of tenderness acceptable to the consumer. Normally, the cooking time required by recently-harvested legumes is taken as the base time.

The softening of food legumes during cooking involves the dissolution or disintegration of the intercellular layers, with the resulting separation of cells (MATTSON, 1946; ROCKLAND and JONES, 1974; KUMAR, et al., 1976; SEFA-DEDEH and STANLEY, 1979; VARRIANO-MARSTON and DE OMANA, 1979).

The intercellular layer is considered to be a structure composed principally of insoluble pectates and pectins, formed by the association of divalent cations, such as Ca and Mg, with pectic substances (LETHAM, 1962) and possibly with proteic material (GISBURG, 1961).

The softening process during cooking involves the ratio of phytic ions, present as Na or K phytates in the intercellular cytoplasm, to insoluble Ca or Mg pectates present in the cell walls or the intercellular layers. This reaction results in the conversion of insoluble Ca or Mg pectates in soluble Na or K pectates (MATTSON, 1946; ROCKLAND and JONES, 1974; KUMAR et. al., 1978; VARRIANO-MARSTON and DE OMANA, 1976).

Logarithmic graphs of pectic substances of the integuments as well as of the cotyledons, in relation to the cooking time, are straight lines, which suggests that the dissolution of pectic substances and the resultant softening during cooking is a first degree reaction (MOSCOSO, et. al., 1984).

In red kidney beans, the constant for the speed of dissolution of pectic substances, in the tegument as well as in the cotyledons, were higher for the control sample, stored with 12,5% moisture content, at 2°C, than for the samples, with 14.9 to 17.9% moisture content at 32°C. The apparent mashing constant presented a high correlation with the apparent dissolution constant of the pectic substances in the integument and the cotyledons. The coefficients were $r = 0.96$ for the teguments and $r = 0.97$ for the cotyledons (MOSCOSO, et. al., 1984). These results support the theory that the changes in pectic substances are responsible for the changes in the cooking quality of food legumes (ROCKLAND and JONES, 1974;

SEFA-DEDEH, et al., 1979). Chelating agents, such as phytic acid or other naturally-occurring substances contained in the intracellular cytoplasm might be involved in the lignin processes of divalent cations in bridge positions in the pectic matrix of the intercellular layers (ROCKLAND and JONES, 1974; VARRIANO-MARSTON and DE OMANA, 1979).

MOSCOSO et al., (1984) indicate that the content of phytic acid phosphorus in soaked beans correlated well with the softening speeds of beans ($r = 0.96$) and with the dissolution speeds of pectic substances in the teguments ($r = 0.95$) and cotyledons ($r = 0.92$).

The loss of cooking quality in beans stored under conditions of high humidity and temperature could therefore result from a decrease in phytic acid and alterations in the relation between monovalent and divalent cations in the tissues (MOSCOSO, et al., 1984).

MATTSON, in 1946, had already postulated that for peans, the increase in cooking time as a function of age was due to the hydrolytic cleavage of phytin through the phytase, forming an inorganic phosphate which would not act as a precipitant of Ca and Mg at the pH of the product. According to the same author, if the pH were slightly increased above 7 by the addition of alkali it would be possible to restore cooking quality to old peas. In addition to the change in the pH, KUMAR, et al. (1978) suggest that the degree of hydration, the stability of complex salts and uronic acids in the cell walls might also have a function in the process of cooking.

For soybeans stored for one year at 75% relative humidity and prepared in the same manner as beans, the average acceptability when evaluated on a flavor scale of ten points (10 very accepatble), the initial score of 8.14 changed to 8.28 after having been stored at 14°C, and to 6.89, when stored at 30°C (SARTORI and ARKOLL, 1976).

In samples of six varieties of beans with moisture contents from 11 to 13%, stored at 25°C and 70% relative humidity, significant deterioration in flavor was found after nine months of storage (MORRIS and WOOD, 1956).

Color

Diverse studies have shown that different varieties of beans vary in their susceptibility to darkening (BURR, et. al., 1968; SARTORI, et. al., 1985).

In beans stored in an open-air environment, the darkening of the tegument tends to increase with the moisture content, temperature and storage period (TOOLE, 1948; BURR, et. al., 1968; JORDÃO, et. al., 1976; VONGSARN-PIGOON, 1979; SARTORI, 1982).

Pinto beans, with a 14.4% moisture content, were stored for six months at 25°C and 75% relative humidity in (1) cotton sacks; (2) in recipients with forced air flow; and (3) in recipients with forced flow of nitrogen. The beans stored in nitrogen maintained the light-colored tegument characteristic of recently-harvested beans during the entire storage period.

In addition to the dissolution of the intercellular layers, the inherent susceptibility of the starch granules and the proteic matrix in the cotyledon cells to be softened during the process of cooking would influence the softening process (ROCKLAND and JONES, 1974; SEFA-DEDEH and STANLEY, 1979). During the cooking of whole beans, the mechanical tensions originated by the process of the starch gelatinization (HAHN, et. al., 1977), denaturing of protein, increase of volume and heat convection would facilitate even more the separation of cells (ROCKLAND and JONES, 1974).

Taste

The taste of beans with 11 to 13% moisture content, stored for approximately twelve months, is significantly improved when the storage temperature is maintained below 20°C. The differences in flavor when beans were stored for one year at 18°C and and 10 - 14° C (JORDÃO, et. al., 1976) as well as at 18°C and 5°C (DEL GIUDICE, et. al., 1972) were not significant.

The flavor of the Carioca variety bean, with an initial moisture content of 12.2%, stored at 70% relative humidity, evaluated by ten testers on a flavor scale of 7 points (7= very good) changed its initial score of 5.1 to 5.2 after nine months of storage at 20°C. For the same storage period at 30°C, the initial score of 5.1 changed to 3.3 (SANTOS, et. al., 1981).

In beans stored under forced aeration and in cotton sacks, there was a signficant darkening of the tegument after 2, 4 and 6 months of storage. However, there were no significant differences between the two treatment styles. The coloring of the teguments, measured by the percentage of relative reflectiveness (Agtron values), is indicated in Figure 2 (SARTORI, 1982). The fact of the darkening of the tegument has not been verified in the absence of oxygen, despite the relatively high temperature - 25°C. This indicates that darkening is not due to chemical reactions of a Maillard type, but to the enzymic oxidation of phenolic compounds by polyphenoloxydase, the only darkening reaction that depends on the presence of oxygen. In beans with reddish tegument, the concentrations of tannin, a phenolic substance, are high (38 - 43 mg/g) when compared with beans with white tegument (1/3 mg/g) (ELIAS, et al., 1972). The oxydation of tannins could be catalyzed by catecol-oxydase, a polyphenoloxydase present in the tegument itself, whose activity depends on the presence of oxygen (LUH and PHITHAKPOL, 1972).

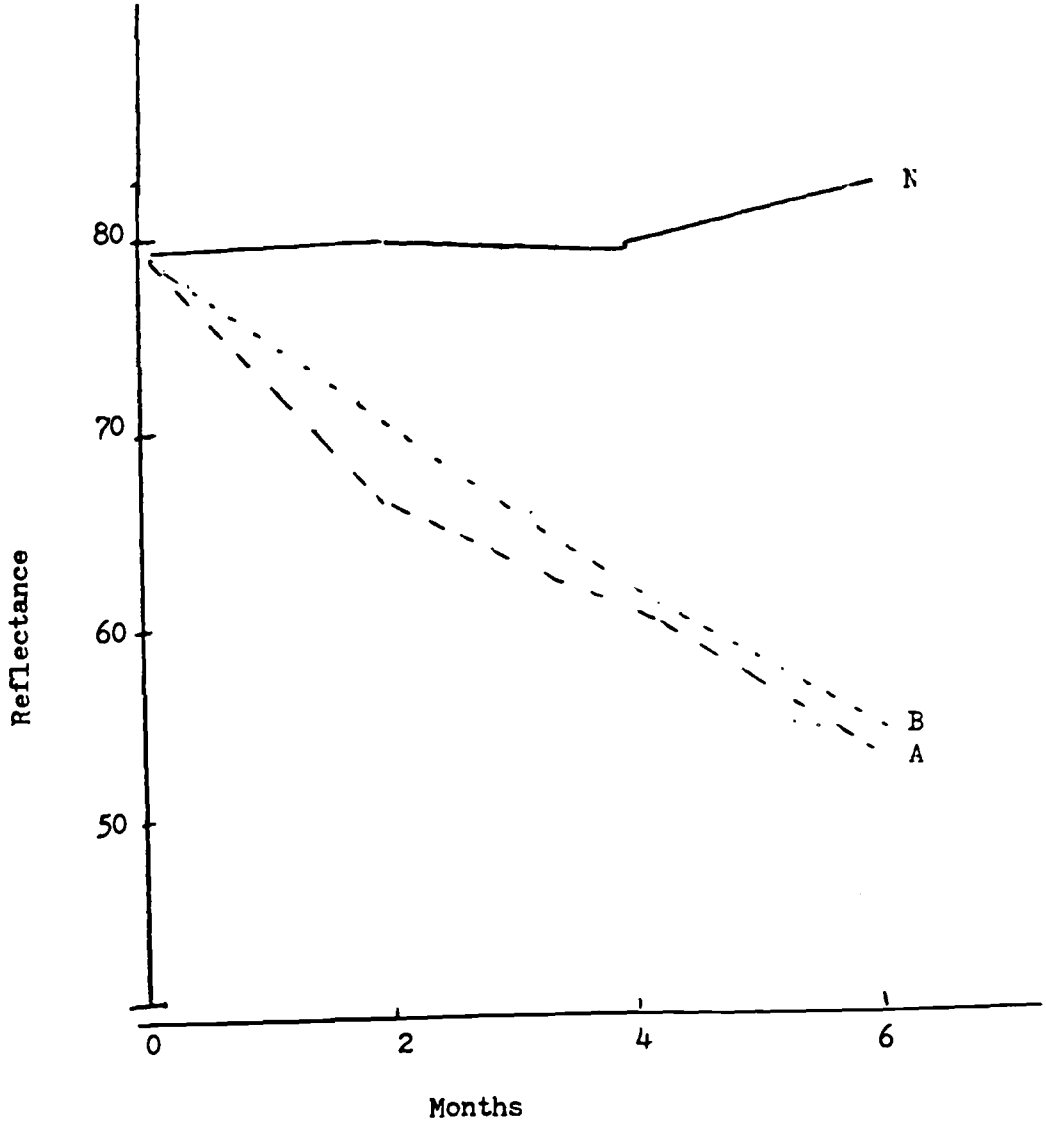

Figure 2 Color (red) of Pinto beans, as measured by the percentage of relative reflectance (Agtron values) after periods of storage at 24°C and 75% relative humidity under forced aeration (A), forced flow of nitrogen (N) and in cotton sacks (B).

SOURCE: Sartori, 1982.

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