THE INFLUENCE OF STORAGE ON QUALITY CRITERIA OF TROPICAL GRAINS

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Abstract

An overview of quality criteria for consumers of cereal grains is given, together with a review of the influence of storage conditions on quality. Consumer acceptance depends on numerous qualities amoung which may be mentioned color, flavor, firmness, elasticity and swelling (water uptake) Chemical tests and physical tests such as amylograph, viscoelastograph, the Instron tester and the texturometer are available to predict the cooking qualities of cereals and their products. However, to evaluate taste and texture, taste panels are also necessary.

In many developing countries hot and humid climates prevail, which lead to deterioration of grain in stores. Under such climates even cereals dried to below 10 % moisture content will not keep well for longer than 2 to 3 months Controlled atmosphere storage at < 0.5 % O2 or confined atmosphere storage will probably provide answers to this problem. However, CO2 may affect grain coloration of rice and no definitive study has been made of the influence of CO2 on corn, sorghum and millet during prolonged storage An on-going research program is being undertaken in Australia and the Philippines on controlled atmosphere and temperature storage of milled rice, paddy, brown rice, corn, sorghum as well as as other commodities Such a program should serve as a model to provide valuable information on the influence of O2 and CO2 tensions in combination with temperature and water activity on grain qualities and end-uses.

It is advocated that the available methods and instruments for quality control should be used for evaluation of grain quality in all future studies of storage, whatever the duration

A Grain quality

1. Definition of grain quality

Acceptability by consumers of tropical cereals namely rice, maize, sorghum and millet is directly related to :

Proc. 4th Int Work Conf Stored-Product Protection, Tel Aviv, Israel, Sept 1986
[Eds E. Donahaye and S Navarro], pp 355-384

- size and shape of kernel, which do not change during storage but depend on variety ;
- milling yield and breackage, which do change ;
- discoloration, flavor, taste, texture and cooking qualities which depend on biochemical changes occuring during storage and also on previous physical treatment that the grain underwent during harvesting, drying, handling and milling ;
- degree of contamination by molds, fungi, insect pests and rodents;
- food habits which differ from country to country and within the country itself.

Grain qualities are defined herewith as characteristics that relate to consumer acceptance or preference when a choice is possible between at least two varieties or consignements of the same cereal.

Rice In Thailand "good quality" usually refers to long slender translucent grain that results in a fluffy tender cooked products. But in Northern-Eastern Thailand consumers prefer waxy or glutinous rice, steam cooked after overnight soaking, rather than boiled. In Japan the most important parameter for measuring eating quality is said to be stickiness and gloss In the Philippines a desirable cooked rice is described as one that remains soft even when cold, is moderately aromatic, white, slightly sticky, glossy, and possesses a moderate to full characteristic flavor. In Senegal, white brokens rice is definitively preferred to head rice , most of the annual 600 000 tonnes of imported rice are brokens from Thaïland.

Sorghum This is eaten in Northern China as decorticated kernels. Sorghum is also consumed daily in South India, East and West Africa from Senegal to Sudan and Botswana in dry tropical zones It is usually eaten in the form of thin or thick porridge or semolina White sorghum is preferred and should be half-vitrous floury, not too hard to decorticate and grind. Red sorghum due to the presence of colored anthocyans is used for traditional brewing

When consignements of american and french sorghum were supplied as food aid in the 70's to the Sahel, they were initially rejected due to their tanin content and their brown colour.

Millet Yellow to brown and greyish varieties are grown in Africa. Preference will differ from one ethnic group to an other. However colour of the milled product is a less important criterion than firmness and elasticity of the porridge made from it, or flour particle size for local couscous

Maize. Maize for human consumption may be yellow in Mexico and latin America for tortilla. In Africa preference will be in favour of white or yellow-white maize varieties in Benin and Togo as well as in Zambia. Maize should be floury rather than vitrous. Imported yellow maize for aid provided by the EEC or the United States was initially discarded but imported grits and semolina were accepted due to their appropriate particle size and were immediately used in substitution for rice brokens or sorghum flour.

2. Quality criteria

Researcher objectives are to relate physical and chemical characteristics of grains to processing and cooking criteria and consumer acceptance, in order to inform geneticians, breeders and agronomists what varietal characteristics they should select and disseminate to the farmers. It is not surprising that cooking and eating qualities of rice have been much more studied than for other tropical cereals. Rice, as wheat plays an international role in food. Maize qualities have been studied essentially for animal feeding, where digestibility and nutrition prevailed over acceptance. Effects of drying and storage on maize have been also studied for the starch industry.

As opposed to rice, millet, sorghum and maize are milled into flour, semolina and grits and the cooking quality has to be assessed on the many traditionnal dishes made from them ICRISAT and national institutes in India, EEC, West and East Africa and USA started to investigate millet and sorghum cooking qualities not more than 15 to 20 years ago. Methods and instruments must be adapted to measure viscosity cohesiveness, hardness of porridge, "tô", "ugali", or steam-cooked millet, maize, or sorghum "couscous". Maize and sorghum made tortilla have been compared in terms of acceptance and cooking quality From the bibliography, it is clear that with the exeption of rice scientific knowledge on the effects of storage on quality of tropical grains is still limited.

To quantify cooking quality several characteristics related to the texture have been defined by researchers.

PHYSICAL CRITERIA

TEXTURE :	- Water uptake/swelling	
	- Firmness/tenderness	COLOUR
	- Viscosity	ODOUR
	- Stickiness	SHAPE
	- Elasticity	

CHEMICAL ANALYSIS

- Amylose/amylopectin
- Gel consistency
- Gelatinization temperature
- Free fatty acids
- Non reducing sugars

Measure of quality criteria related to consumer

Physical and chemical tests are available to try and quantify the cooking quality of non gluten cereals. Some of them are modified methods and apparatus used for wheat flour and dough such as the Amylograph, but rice grain, maize, millet and sorghum flours may require specific methods to assess and measure physical and chemical characteristics that are thought to be relevant to quality and behaviour of cooked products made from them. The most common methods for assessing the product texture are briefly described hereunder

Physical tests

Water uptake does not raise specific difficulties, but texure evaluation is much more subtile and several methods are proposed.

a Water up-take _ swelling

The simplest method consists of cooking at 100°C a weighted quantity of rice, say P1 = 1 5 g of head rice in a tea-bowl. It is convenient to select two cooking times normal and overcooking times Final weight of cooked rice being P_2

Water uptake will be given by $W = \frac{P2 - P1}{P1}$

Swelling will be given by $W = \frac{P2}{P_1}$

Swelling values usually are between 150 and 240 for cooked rice and may reach 330 for over cooked rice depending upon variety

b Firmness/tenderness

These characteristics are sometimes named by researchers hardness/softness

I) Precision penetrometer (sorghum, maize, millet)

This equipment was used by Da et al. (1981) for evaluations of tô quality in a Sorghum Breeding Program, sponsored by ICRISAT. Tô of Sahelian countries (Tuwo in Nigeria) is generally made from sorghum flour prepared from decorticated grain. The flour is cooked in water that is acidified or in alkali solution depending upon the region. Tô can also be made from maize and millet. It is allowed to cool about 1 hour after cooking before it is consumed with a sauce. The consumer wants tô to be with firm paste which does not stick to the fingers and teeth. Firmness should remain constant overnight It differs from one variety to another

Slices of tô samples 11 mm thick on a hard plate surface are placed under the penetration cone of a precision penetrometer (precision Scientific Co Chicago, USA) calibrated in 0 1 mm divisions The tip of the reverse cone is lowered until the tip just touches the surface of the tô. Then the cone is released by a lever and allowed to free fall into the tô Divisions are read 2 sec. after the fall. The cone penetrates deeper into a soft tô than into a firm tô. Softness in this case ranges usually from 40 units (firm tô) to 90-95 (soft tô).

This measure could also be used to define Ugali texture in East Africa Ugali is a thick porridge made from maize flour.

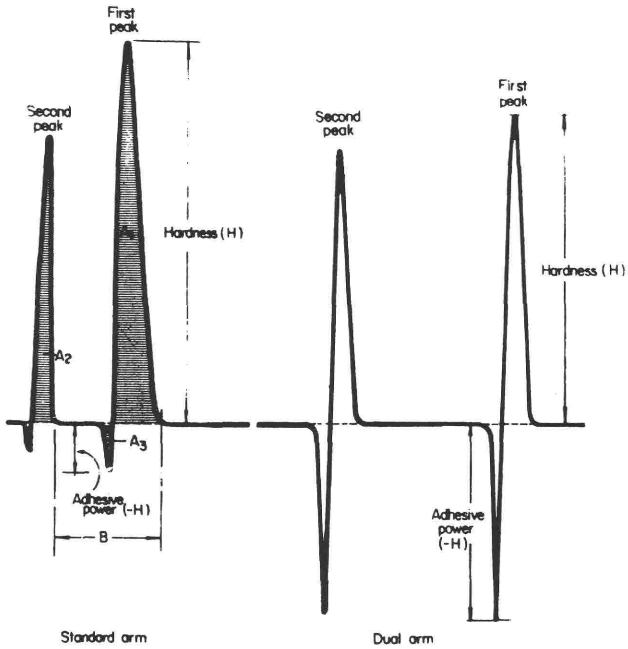
II) Texturometer (rice)

This consists of a mechanical masticator, a standard or dual arm, holding the plunger driven by motor and a fast speed recorder. The force-time curve indicates the behaviour of the test food under the chewing action of the plunger Three replicates are used with one whole grain of cooked rice at a time

From the Texturometer curve of the first and second chew (Fig 1), hardness is measured form the profile as the height of the first chew normalised to a 1-volt input. Adhesiveness is the area in arbitrary units (A3) of the negative peak below the baseline of the profile after the first chew and represents the work necessary to pull the plunger from the sample Adhesive power is the height of this negative peak Cohesiveness is the ratio of the area, in arbitrary units, under the second peak and the area under the first peack (A2/A1). Springiness or elasticity is measured as the difference between the distance (B) from the initial sample contact to the contact on the second chew, and the distance (C) for the same measurement made on a completely inelastic standard material such as clay. Gumminess is expressed as the product of

hardness and cohesivenes.

Fig. 1 : Texturometer curves by standard arm and dual arm.



III) Instron tester

Instron Ltd, High Wycombe Bucks, UK, has developed an Instron tester specifically for food texture testing. It was used by Perez and Juliano (1982) with a modified test cell for cooked rice. The mechanical drive system is a horizontal crossbead going vertically up and down. The forces generated either in compression or tension are recorded. Duplicate 17 g cooked rice samples are placed in the test cell and pressed with a standard weight for 1 minute before extrusion. Hardness is defined as the maximum force (in kg) needed to extrude the cooked rice through the cell's perforated base at a standard cross head speed.

c. Stickiness or cohesiveness

I) Instron tester

Stickiness can be measured on an Instron Tester by using a special plunger which presses whole cooked rice for 10 sec onto a platform. Stickiness is expressed as the product of the force in g required to

lift the plunger and the distance in cm that the plunger traverses. This method was used by Tanaka (1975), Lisch and Launay (1975), Okabe (1979). The Instron tester can be used also for tô from sorghum flour or maïze.

II) Double pan balance

Texas A M Laboratory used the simpler beam balance method described by Kumar et al., (1976) for measuring the stickiness of bread crumbs

It consists of a double pan balance. A slice of tô on a flat surface is placed in contact with a disc fixed under the left pan and the balance pointer is zeroed. Water is added in a beaker on the right pan When the weight of water overcomes the adhesion of the disc-Tô interface the pointer goes off the scale.The position of the pointer just before the break is reported as tô stickiness. The higher readings indicate tô with a greater stickiness.

d Firmness and elastic recovery

Viscoelastograph

The Chopin-INRA Viscoelastograph is an apparatus that has been developed by INRA (France) for evaluating the viscoelastic properties of food products (Feillet et al, 1977 ; Laignelet and Alary, 1978). Samples are compressed between two plates with a selected load and for a selected time The change in thickness of the sample relative to the time during and after loading are recorded on the Viscoelastogram, which is a strain-time curve The following parameters are measured : initial thickness R (mm) , thickness e1 (mm) before loading off ; final thickness e2 (mm) (Fig 2) Then, firmness (F) and elastic recovery (ER) are calculated by the equations

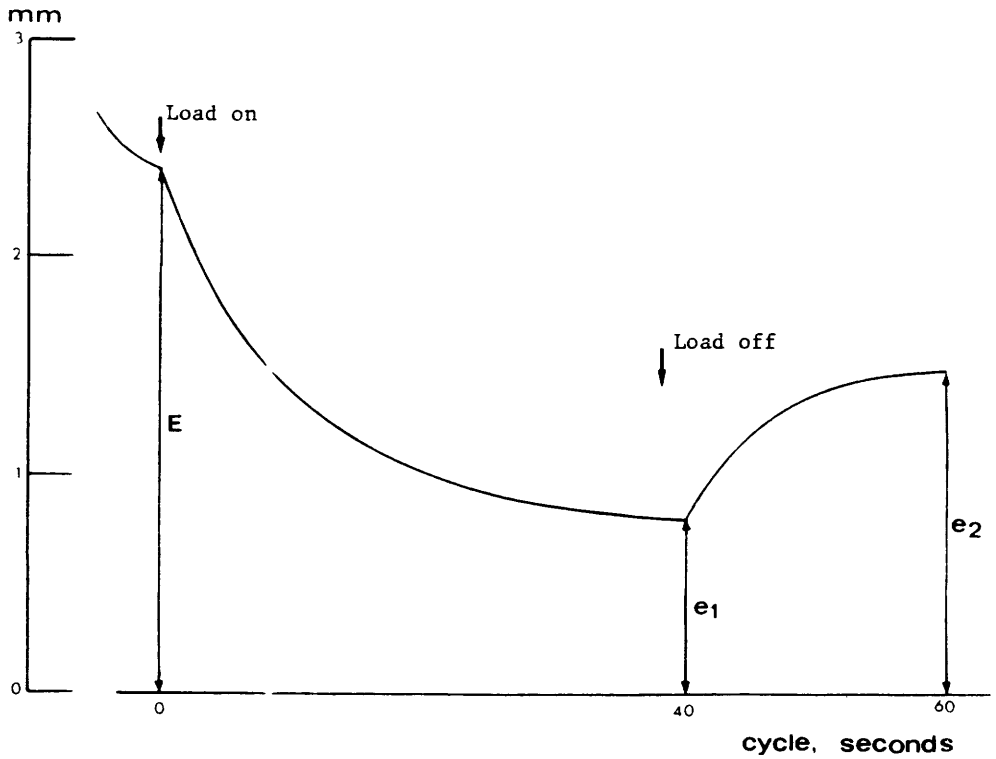
$$F = 100 \times (e1/E) \qquad ER = 100 \times (e2 - e1)/(E - e1)$$

Three grains of cooked rice are placed on the Viscoelastograph sample holder Then, the Viscoelastogram is recorded. The same measurement is made three times for each cooking time. High elasticity indicates that the structure of cooked grain remains partially after crushing, which means that the binding strengths between rice components are high. Results are correlated with those obtained with a Kramer Shear Press (Lisch and Launay, 1975) (similar to the Instron tester).

Firmness values generally range between 20 and 70, elastic recovery from 4 to 25 The instrument can also be used for other products such as

cooked pasta or couscous.

Fig. 2 : Viscoelastogram of cooked rice. From Feillet et al., (1977)

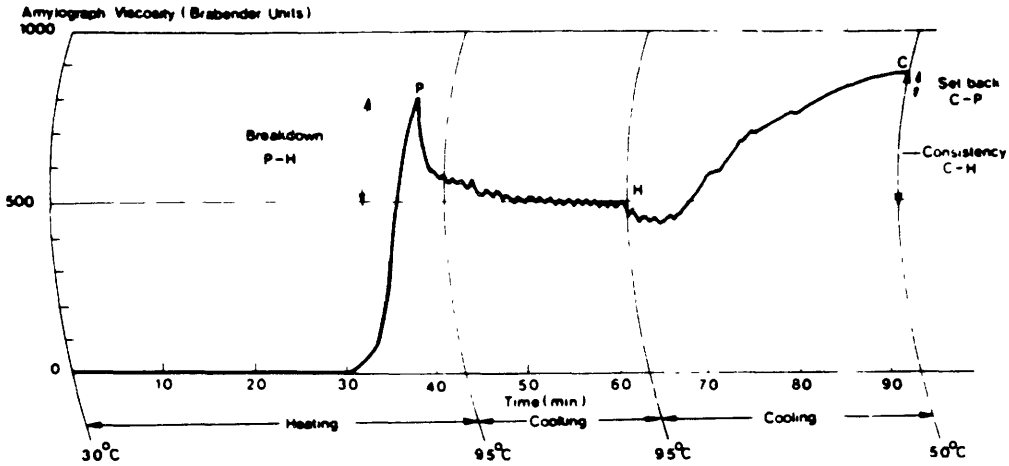


As with the texturometer and the Instron tester for measurement of stickiness, whole cooked rice is used for viscoelastograph measurement this being an advantage.

e. Viscosity

The instrument used here is the Brabender Amylograph. Milled rice is mixed with water. The slurry is transferred to the Amylograph bowl and heated from 30°C to 95°C at 1.5°/min. Temperature is held at 95°C for 20 min and then the paste is cooled to 50°C at the same speed (Fig. 3).

Fig. 3 Graphical representation of an amylograph of 10 % milled rice flour and viscosity values derived from it. P = peak viscosity, H = final hot paste viscosity at 95°C, and C = viscosity cooled to 50°C.



Values of interest are pasting temperature, peak viscosity, breakdown, consistency, and setback. Pasting or "gelatinization" temperature refers to the temperature at the intial increase in viscosity of the rice paste. Breakdown is the difference between peak viscosity and minimum viscosity after the peak whereas consistency is the difference between final viscosity on cooling to 50°C and minimum viscosity of paste Setback is the difference between final viscosity on cooling to 50°C and peak viscosity. Juliano et al., (1966) pointed out the positive correlation between amylose content and amylographic setback value of rice flour, viscosity on cooking and final viscosity after cooking at 95°C for 20 minutes

Pasting temperature for japonica rice flour is generally lower, (62-67°C) than for indica (62-76°C). Generally rice flours with lower peak viscosity, breakdown and consistency show desirable eating quality Pasting temperature and breakdown could be selected as index factors for palatability evaluation

f. Gelatinization temperature

Gelatinization temperature is a physical property of starch and is the range of temperature within which the starch granules begin to swell irreversibly in hot water Final gelatinization temperature ranges from

low : 55°C to 69°C to intermediate : 70°C to 74°C or high 75°C to 79°C. Gelatinization temperature and cooking time are positively correlated (Juliano, 1979) and there seems to be a preference for the variety with intermediate gelatinization temperature, between batches of rice of same shape, size and amylose content.

Chemical tests

a. Amylose content

Scientists have tried to relate rice quality to chemical composition of the grain. The amylograph test indicates already the importance of amylose. In fact protein and amylose content are two of the most important determinants of grain quality in rice. The eating quality of cooked rice is determined largely by the amylose/amylopectine ratio of the starch Juliano et al. (1966) and Perez (1979) have shown a relationship of hardness and stickiness to amylose in cooked rice (Fig. 4). However differences in texture has been observed among rice of similar amylose content and another chemical test was used : the gel consistency test.

b. Gel consistency

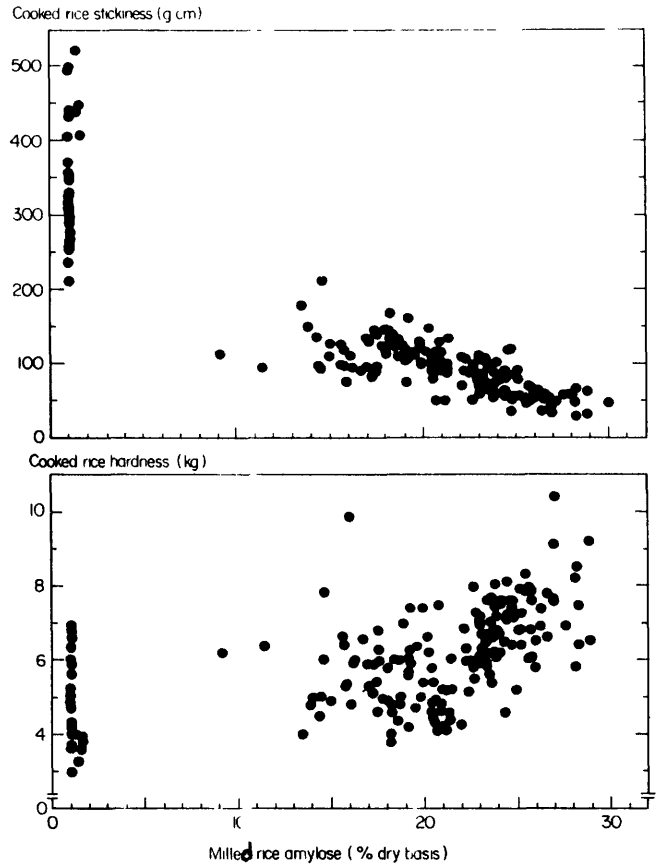
Gel consistency is the measure of flow characteristics of milled rice gel in alkali solution The length of the horizontal cold gel is measured. Gel is classified as hard (26-40 mm length) medium (41-60 mm) and soft (61-100 mm). This classification correlates with Amylograph Consistency or the increase in viscosity of rice paste on cooling from 95°C to 50°C. Among high amylose samples, differences in hardness correlate with differences in gel consistency (Juliano et al., 1964 , Cagampang et al., 1973). Soft gel is generally preferred over hard gel in India and Sri Lanka. Intermediate-amylose rices are preferred by Filippinos, Indonesians, Thais, Vietnamese, and Malaisians (Juliano et al., 1964. The cooked rice remains short even when stored overnight, although it is slightly sticky. These rices may have low to intermediate and intermediate/high gelatinization temperatures. Low-amylose rice is preferred in Japan and South Korea for its stickiness, tenderness, gloss and taste. Besides amylose content, differences in gel and Amylograph consistency or gelatinization temperature may be related to hardness differences of cooked rice (Perez, 1979).

c. Free fatty acid

The production of free fatty acids (ffa) during storage provides information on the actual condition of the fats. It is due to hydrolytic

deterioration of grain by lipase. The fatty acids, in turn become oxidized by lipoxygenase causing rancidity The peroxidase value is a measure of this deterioration

Fig. 4 : Correlation of amylose content with stickiness and hardness of cooked rice (Instron food tester). From Juliano, (1979).



d. Non reducing sugars

These are known to increase during storage particularly at a high temperature (35°C). Sugar content of grain may not be related to consumer acceptability

Conclusion

To conclude on methods for measuring eating quality of rice and other tropical cereal products.

- Methods are available to assess behaviour of grains and products during cooking. The terminology however is not always clear as for instance to what is stickiness, adhesiveness or cohesiveness.
- It is still possible to improve knowledge of biochemical composition of products and their relationship to physical characteristics as functions of cooking quality.
- However consumer reactions depend on habit. Off-flavor and colour in addition to unusual texture are deterrents to many. Taste panels are in any case necessary to score the sensing of texture evaluation against analytical tests

B Changes in grain quality during storage

In many developing contries hot and humid climates prevail and are favourable to deterioration, and neither the know-how, nor modern physical facilities are available to reduce or eliminate losses. Temperature and relative humidity (r.h) of the air, and initial moisture content (m.c.) of grain greatly influence the storability of cereals. Many authors have studied the changes in quality of wheat grains and flour during storage. Many less have published on changes of stored maize and rice and only a few papers are available on storage of millet and sorghum grains and flour.

Regarding prolonged storage periods, the situation is even less satisfactory ; results have been published on grains stored for more than 8 to 12 months but only under temperate climates or what is sometimes called "normal conditions". They give some indications on baking qualities of wheat flour Very little is published on prolonged storage of rice, maize, sorghum and millet or wheat in tropical humid climates and practically nothing on their technological or cooking and baking qualities The researchers may have good reasons to stay out of these fields of investigation . experiments have to go on for many years and the economics of prolonged storage are not there to justify government spending and interests of private firms.

1. Storage of wheat and wheat flour

It may be of interest to mention briefly one or two results on wheat before moving to tropical cereals.

There are several reports on storage without damage of wheat and

flour for up to 10 and even 27 years, and in various types of packaging (Pixton et al., 1975). Experiments were carried out under normal conditions which usually means dry grains at 12-13 % m.c. maximum, stored at 20°C or below held at equilibrium relative humidity at the most. During prolonged storage, protein content decreased slightly, fat acidity increased. There was no decrease in wet gluten but opinion on decrease of diastasis acidity and loaf volume were controversial. Differences however are said to be not larger that might be expected from different crop years.

Popineau (1972) studied the relationship between date of harvesting of mature French Wheat and flour strengths (W) after 12 months storage of the grain. The (W) increased for early harvested wheat during storage, but decreased for the wheat harvested 20 days later (Fig. 5). The dates of harvest (related to grain maturity) greatly influenced wheat quality after 6 to 12 months storage. Similar studies should be made for rice, maize and sorghum for human consumption.

Bothast et al. (1981) stored wheat-flour and corn-meal in tightly capped bottles at m.c. ranging from 11 to 18 % and temperatures of 25 to 34°C for 18 months Product quality namely odor and flavor could not be maintained beyond 9 months for wheat flour and 6 months for corn meal at 15 % m.c. and 25°C. When stored at 18 % and 25°C, both products deteriorated in 15 days. Changes were more rapid at 34°C (2-3 days).

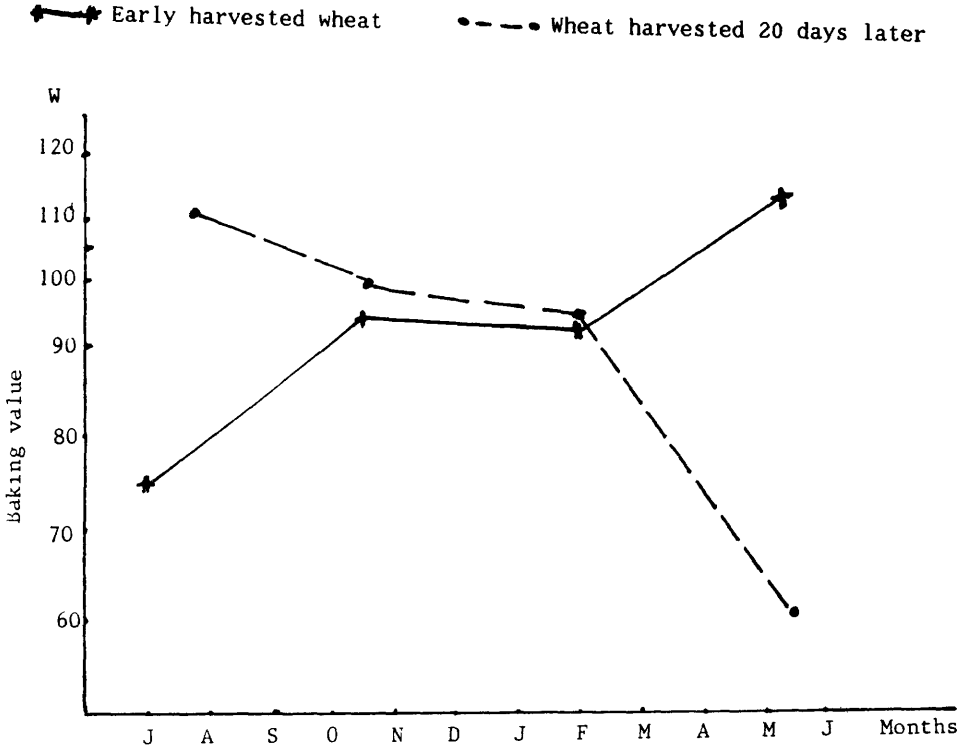
2 Storage of paddy under adverse conditions

INRA and IRAT (France) undertook studies of the technological characteristics and cooking qualities of paddy stored 6 months under conditions close to a tropical humid climate . r h. ranged from 72 % to 93 %. Storage temperatures were (i) 30°C constant (ii) fluctuating between 25° and 40°C. Air-tight storage and propionic acid were also used (Syarief, 1983).

Other conditions were as follows

- Equilibrium moisture of paddy : 13 % m.c. at 72 % r.h. ; up to 19 5 % m c at 93 % r h. For confined storage and propionic acid : 16.5 % m.c.
- Alternate temperature · 2 hours from 25°C to 40°C, 10 hours at 40°C, 2 hours down to 25°C, 10 hours at 25°C.
- All technological and cooking tests were conducted after the samples of paddy were returned to 13 % m.c. at 20°C and 70 % r.h. in an air conditioned room.

Fig 5 Change in baking value (W) of early and late-harvested wheat stored fror 10 months. From Popineau, (1972).



i) Results at constant temperature of 30°C

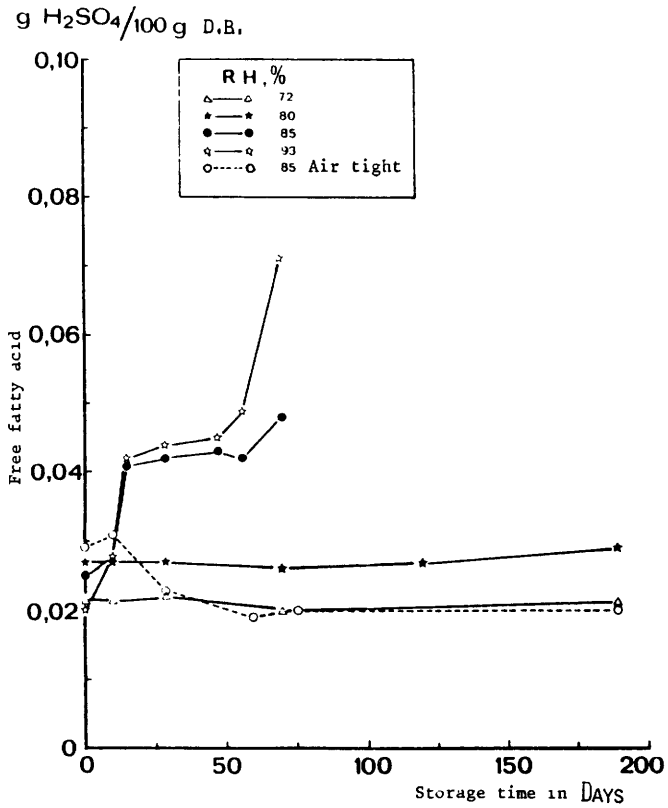
- Free fatty acid content increased slowly below 80 % r.h. The equilibrium moisture of paddy was around 14.5 to 15 % wet basis and only grain lipase was active. At higher r.h., lipase produced by microorganisms played a predominant role (Fig. 6).

- Milling characteristics were pratically unchanged after 200 days of storage below 80 % r.h. They were significantly modified when temperature and r h. of storage allowed molds to develop. The milling yield in this case which was 55 % at 72 % r.h. decreased to 37 % at 93 % r.h. (Fig. 7)

ii) Results at alternating temperature (25-40°C)

- Fungal development was much faster than at constant temperature of 30°C. This development was increased by higher r.h.

Fig 6 Changes in free fatty acid content during storage of paddy at 30°C under different relative humidities From Syarief, (1983)



- Toxigenic molds appeared at 85 % r h. Aflatoxin B1 was present after 1 to 3 weeks depending on the r.h and only after 4 to 8 weeks at 30°C constant temperature

- Free fatty acid content increased faster than at 30°C (Fig. 8).

- Milling characteristics were significatively changed due to water sorption and desorption variations (Fig 7) but cooking qualities remained similar to those of paddy stored at 30°C

Further findings were .

- Swelling or water uptake of cooked rice tended to decrease when r.h. was higher at constant and alternating temperatures (Fig. 9).

- Firmness and elastic recovery increased with r.h. and storage time at constant and alternating temperatures (Fig. 10).

- Firmness and elastic recovery were improved by the use of

propionic acid. Swelling was lower.

- When stored in an air-tight container or with propionic acid milling yields remained stable during the 200 days storage period (Fig. 7).

The generally negative effects of temperature fluctuations on storage, milling yields and cooking qualities of paddy were clearly illustrated. Deterioration was accelerated.

Similar studies would be welcome for other tropical grains. Prolonged storage of above 6 months at 80 % rh in air tight containers should be investigated in relation to quality criteria.

3. Changes in storage of paddy and brown rice

Christensen and Lopez (1965) reported that the equilibrium moisture content is about 13 9 % for paddy and 14 9 for brown and polished rice at 80 % r h. and 22-25°C. The lower equilibrium moisture of the husk may help in protecting the kernel, acting as a barrier to the penetration of humidity and fungi The husk prevents also the grain from becoming rancid by protecting the brown layers from mechanical damage during harvesting, handling and storage

In a review paper entitled : Implications of rice kernel structure in storage, marketing and processing (1978), BECHTEL and POMERANZ wrote the following : "When paddy is dehulled, the brown rice may become rancid. As long as the bran is intact and protected by the husk, there is little lipase activity. Rice aleurone cells are susceptible to disruption during dissection which results in lipid body fusion Possibly, the dehulling process and subsequent milling and handling of the rice disrupt the aleurone cells which leads to rice rancidity. For example, Houston et al (1952) found that brown rice from rubber roll shellers stored better than rice dehusked by an emery coated disk sheller".

It is known that well milled rice keeps better than under-milled rice. Deteriorative changes (discoloration, rancidity, odours, etc.) which occur in undermilled rice reside primarily in the bran layers left on the rice (Barber, 1972). Watson et al. (1975) found that small differences in degree of milling resulted in substantial differences in surface lipid content, 0.99 % for undermilled versus 0.63 for lightly milled. Yellow rice results from heating of stored unthreshed grain. It is probably caused by fungal respiration at very high humidity with increasing m.c.. At 25°C and below changes are small, even at relatively high moisture level.

4. Changes in storage of white rice

a) Colour and odour

Primo et al., (1970) stated the following about colours and odours of milled rice stored 6 months or longer :

- White rice can held for one year under air, nitrogen, oxygen and carbon dioxide atmospheres and undergo very little colour changes at 2°C and 20°C, but all samples developed a marked yellow colour at 25°C indicating that coloration is not only due to hull pigments but may be attributed to Maillard reactions (non enzymatic browning reaction of proteins with reducing sugars in surface layers).
- Unlike colour, odour changes relatively soon and off odours are influenced by m.c., temperature and also milling degree since they are related to changes in free fatty acids of the grains.

b) Changes in cooking qualities

The Rice Institute in Valencia, Spain, studied extensively these changes in the 60's and 70's. The results obtained by Primo et al., (1970) are the following They refer to storage duration not exceeding 12 months (Table I).

Storage of milled rice affects the physicochemical characteristics of the kernel. Water absorption during cooking and expansion of cooked rice increase for old rice but require longer time for cooking than fresh rice. Total amount of solids eluted during cooking decreases, both moisture content and temperature accelerate the changes. The gelatinization temperature, as given by the amylogram, hardly varies. In contrast with this, other characteristic points of the amylograph display significant changes. Old rice yields pastes of higher peak viscosity, minimum viscosity and viscosity at 50°C. There is some indication, however, that under extreme conditions, some deviations from the general behaviour might occur.

c) Prolonged storage of milled rice

Little information is available concerning physical and chemical changes occuring in rice during more than 1 year storage (Bolling et al., 1978). Six rice samples were packed in 10 kg lots in paper and jute bags and stored at 20°C for seven years. Unfortunately degree of milling nor maturity of harvest nor the r.h. are given. There were no significant differences in rice quality between jute and paper packings Consistency of cooked rice measured with a Haake consistometer (Hampel, 1965) is significantly correlated with sensory test and increased

Fig. 7 : Changes in milling yield during storage of paddy at 30°C in relation with increased relative humidity. From Syarief, (1983).

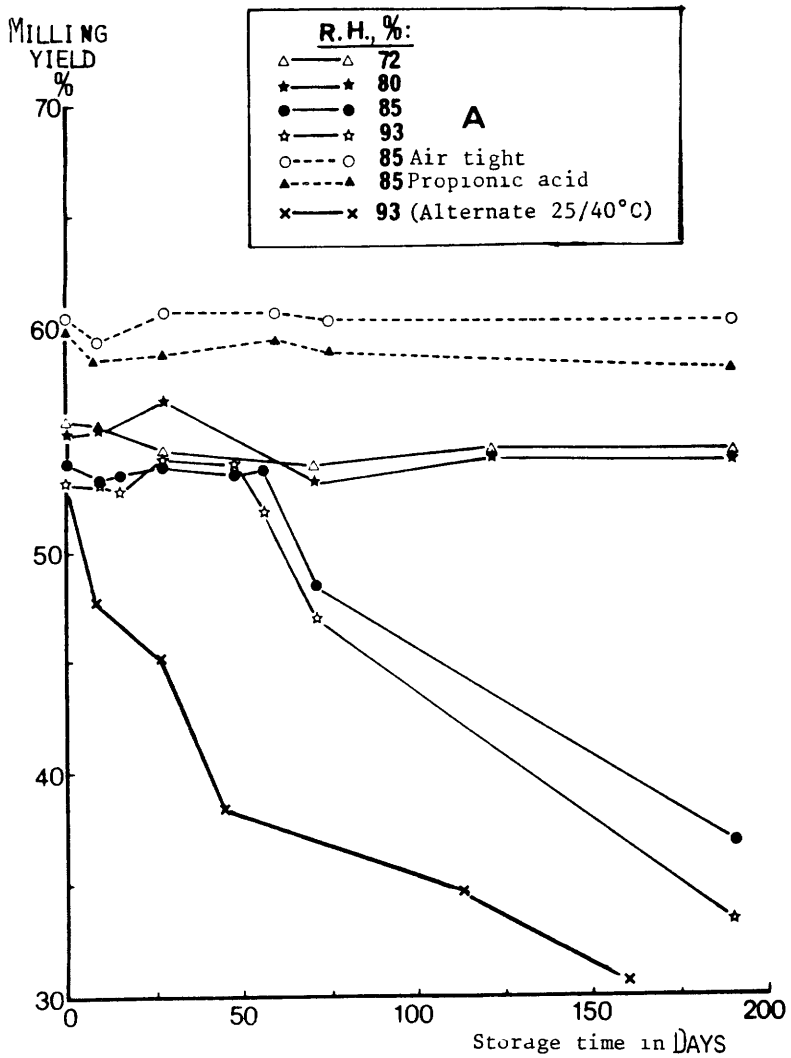


Fig. 8 : Changes in free fatty acids during storage of paddy under alternating temperature (25-40°C) and different relative humidities. From Syarief, (1983).

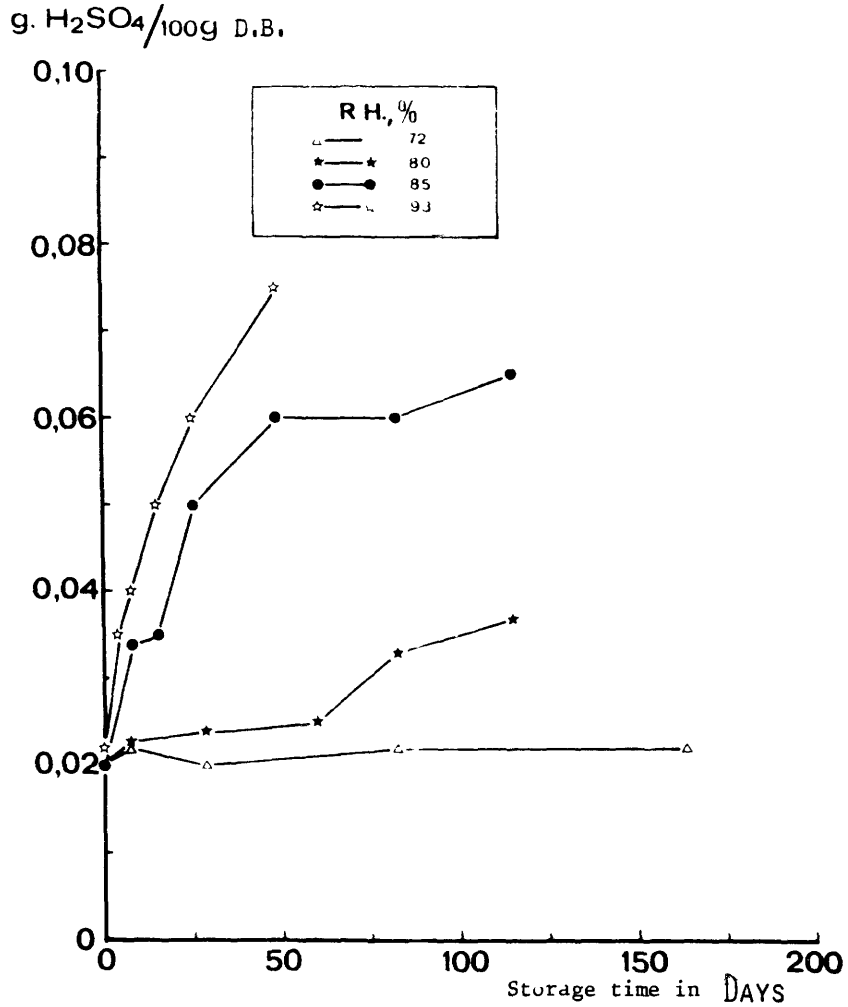


Fig. 9 : Influence of storage duration, relative humidity and alternating temperature (25-40°C) on cooking quality of paddy : swelling index of rice cooked 15 min From Syarief, (1983).

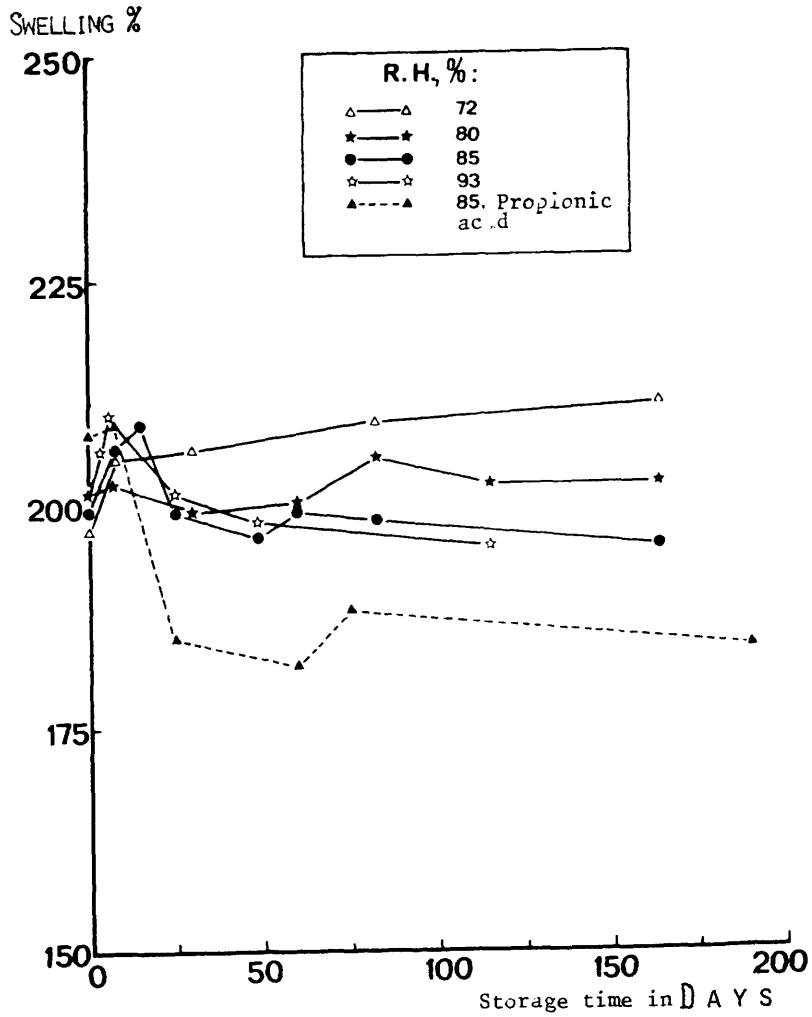
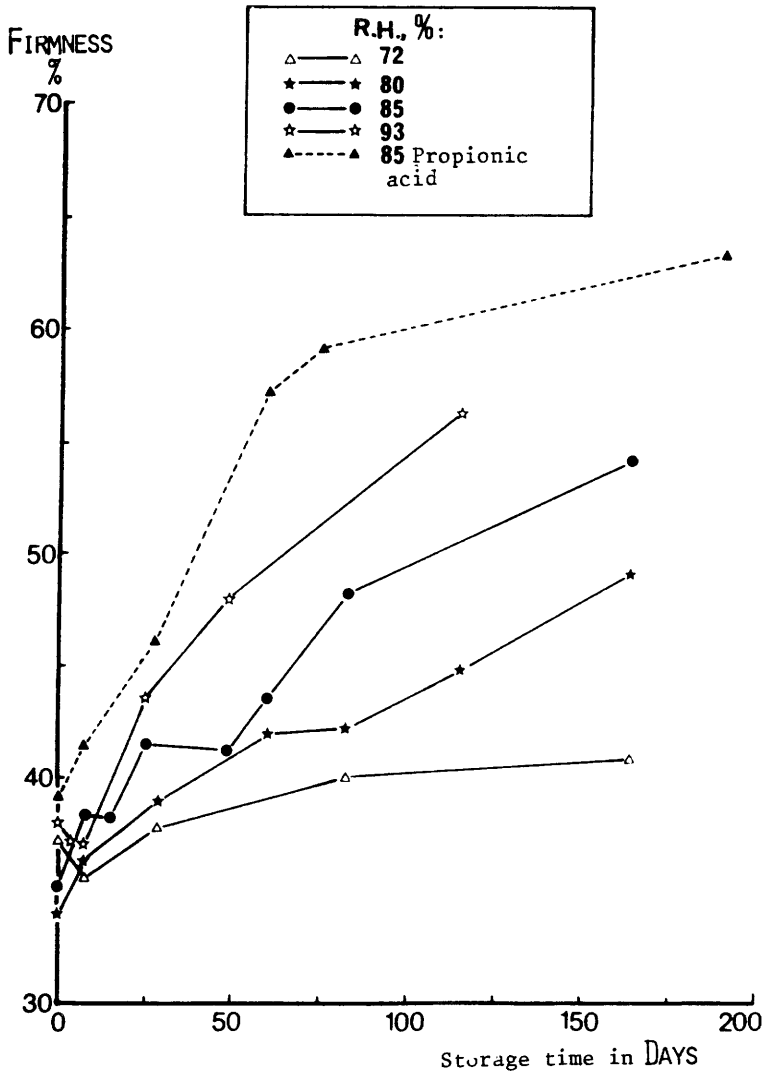


Fig. 10 : Influence of storage duration, relative humidity and alternating temperature (25-40°C) on cooking quality of paddy : firmness of rice cooked 15 min. From Syarief, (1983).



during 2-3 years and decreased a little afterwards indicating that storage causes cooked rice to have a harder texture (Table II). In general gelatinization temperature increased during the first 2 years more than in the following years.

TABLE I - EFFECTS OF 6 TO 12 MONTHS STORAGE ON RICE

Characteristics	Effects
Cohesiveness	-
Water uptake	+
Volume of cooked kernel	+
Solids from cooking	-
Alkali soluble proteins	-
Susceptibility to trypsin attack	-
Amylose	=
Hot paste viscosity of rice flour	-
Hot paste viscosity of rice starch	=

Legend . + increase ; - decrease ; = stable

From Primo et al., 1970.

Swelling decreased up to 4 years and seems to stabilize afterwards For all varieties of rice f.f a started to decrease after the second or third year. This may be explained by their degradation or by the formation of complexes with amylose, increasing the consistency values. A signifiant decrease of soluble proteins to almost half the original values has been observed (Tables III and IV).

TABLE II - EFFECT OF STORAGE ON THE CONSISTENCY OF RICE[6]

Consistency : cP x 10

Samples stored at 20°C	Storage period in years					
	0	1	2	3	4	7
China (short grain)	2.0	3.3	8 0	4.2	5.5	5.3
Originario	3.7	4.2	7.5	9.7	7.9	7.5
Egyptian	2.6	3.4	4.9	8.5	3.5	5.0
Rinaldo Bersani	2 0	2 0	7.2	4.5	3.4	3.7
Super Patna	11.2	9.7	16.3	12.0	11.5	23.5
Blue Bonnet	11 6	11.1	19.7	9.3	11.1	16.7

From H. Bolling et al., 1978.

Odour of the uncooked rice was normal up to the first year (which means that afterwards it was not). However after cooking, all samples were found acceptable in odour and taste

Storage of milled rice results in decreased cohesiveness, drier surface and firmer texture of cooked kernels. The rate of changes depends on m c. and temperature. The influence of the latter predominates at certain levels ; at 10° to 15°C or below, rice remains practically unchanged for long periods. Varietal differences in the rate of changes have been reported but trends appear to be common for all rice varieties Nevertheless, deviations may occur depending upon the initial condition of the grain, particularly on microbial contamination.

Storage can have, even in the absence of deterioration, desirable or undesirable effects according to consumer preferences. For people preferring rice with cohesive properties, such as in Japan, Korea, Taiwan and parts of China, storage changes are undesirable. Cold storage of rice prevents them and this is one reason why this pratice is considered of interest in Japan. On the other hand, for people

preferring non sticky rice, storage has beneficial effects

TABLE III - Effect of storage on the acetic acid soluble proteins of rice

Samples stored at 20°C	Acetic acid-soluble proteins %				
	Storage period in years				
	0	1	2	3	7
China (short-grain)	2.79	2 80	2.48	1.57	1 44
Originario	2 26	1 83	1.90	1.39	1 33
Egyptian	2.74	1.97	2 11	1.50	1.57
Rinaldo Bersani	4 06	3.78	3.37	3.16	2.03
Super Batna	2.33	1 59	1.33	1 26	1 33
Blue Bonnet	2.47	1.83	2 03	1.63	1.58

From Bolling et al., 1978

5. Changes in millet flour during storage (Table V)

Information available (Carnovale and Quaglia, 1973 ; Chaudhary and Kapoor, 1984, Boora and Kapoor, 1985) refers only to short duration of storage. As expected whole grain flours stored for 14 days became rancid on or about the 7th day and inedible around the 12th day depending on varieties and packaging. Flour stored in polyethylene bags was less affected than in gunny sacks. Storage was at a room temperature of 20°C +/- 5°C and r.h. of 60-65 %. Initial flour moisture was 8 %. Thus:

- Although rather low initially, the moisture of the flour rose to 25 %.
- The fat content of whole meal flour was high, 6 to 8% and a high increase in free fatty acids and peroxide leading to rapid rancidity was observed.

TABLE IV - Effect of storage on the fatty acid numbers of rice

Samples stored at 20°C	Fatty acid numbers				
	Storage period in years				
	0	1	2	3	7
China (short-grain)	36	58	65	45	37
Originario	25	43	51	39	21
Egyptian	68	80	96	76	53
Rinaldo Bersani	32	24	25	21	14
Super Patna	22	40	57	56	45
Blue Bonnet	23	29	42	41	29

From Bolling et al , 1978.

- The protein quality deteriorated but differed significantly between varieties after storage A cultivar with higher oil content was more prone to deterioration in protein quality.

Nothing has been published on the effects of storage of sorghum and millet grains on cooking qualities

6. The effect of modified atmosphere for storage

Results from Syarief (1983) on confined atmosphere storage were given above Modified or controlled atmospheres also greatly extend the period of storage for healthy grains. These methods require gastight facilities which are more expensive and scarce in developing countries. They should nevertheless be considered for strategic silos and warehouses Investments might be higher than in traditionnal storage methods, but the operating costs may be significantly lower since chemicals for insecticide treatment are not required.

TABLE V - Storage of pearl millet meal

RH	58 %	64 %	75 %
T°C	19°C	27°C	42°C
Final grain moisture	11 8 %	11.6 %	11.7 %
Panel detection of odour after	108 hours	60 hours	12 hours
Fat acidity ·			
- initially	Equal for all samples at 20 mg KOH/100 of meal		
- at time of detection	Equal for all samples at 30 mg KOH/100 of meal and coincided with the end of induction period for peroxide formation		

From Lai and Varianno-Martson, 1980

Studies of wheat and maize storage at various moisture contents in air-tight stores under nitrogen and carbon dioxide have been carried out by many researchers in Europe, the United States and Australia All authors are concerned by the effect on insects and fungi and make no reference to grain quality acceptability However Lombardi et al., (1976) studied the effect of nitrogen storage on the technological characteristics of wheat They indicated that starch degradation into reducing sugars seems independent of the interstitial atmosphere of grains and continues during storage thus lowering the technological quality of stored moist grains.

Yanai et al., (1979) investigated the changes of chemical constituants and carried out a sensory evaluation of brown rice stored 2 years under various conditions · when compared with the control in ordinary package under atmosphere pressure, the nitrogen atmosphere package caused slightly more fat acidity of the brown rice after 2 years at 10°-20° and 25°C and intial m.c. of 14.5 % and 16.6 %. However rice stored in nitrogen was superior in respect to palatability. There was no

noticeable difference in quality between brown rice stored in nitrogen or carbon dioxide (Table VI).

TABLE VI - Changes in characteristics of brown rice during hermetic storage for 2 years

Duration	1 year				2 years			
Temperature	20-25°C				20-25°C			
	Air		N2		Air		N2	
Initial moisture content	14.5	16.6	14.5	16.6	14.5	16.6	14.5	16.6
Gas composition in in pouches								
O_2 (%)	1 4	1.6	0	0.2	1.2	0.7	0	0
CO_2 (%)	2.1	22.2	0.4	19.5	3.5	28.1	1.0	16 5
Germination (%)	56	0	51	0	0	0	0	0
Reducing sugars (a)	238	655	246	679	328	849	305	856
Fat acidity (b)	43.0	62 4	55 0	60.5	68.7	95 4	83 6	104.7

(a) : Initial reducing sugars 221 mg eq. glucose per 100 g dry rice
(b) : Initial fat acidity 16.8 mg KOH for 100 g dry rice

From Yanai et al., 1979.

7. Perspectives

To the best of our knowledge, further results have not been published. Quality of grain after prolonged storage, particularly for tropical cereals, remains to be assessed. It can be reasonably expected that observations made on periods shorter than a year provide indication on trends beyond that period :

a Under "normal conditions", after 12 months :

- Reducing sugars whose content has increased in the first six months, will become stabilized after one year, the total sugar content being also constant.
- Protein content will slowly decrease.
- Free fatty acids will continue to increase and lipoxygenase activity will lead to rancidity and off flavors not acceptable to consumers.
- Milling yields and swelling will continue to decrease at slower rate. Firmness will increase slowly.

b. Under dry tropical climates, grains are harvested and stored at low moisture contents often 10 % or below. It is known that millet and sorghum can be preserved for more than 2 years in traditionnal grain stores in the Sahel, provided pests and rodents are kept under control The cooking qualities are still acceptable to consumers, although the porridge "tô" become less elastic and appreciated.

c. Under hot and humid climates, even cereals dried below 10% m.c. will not keep well over 2 to 3 months. The answer is probably controlled atmosphere below 0 5 % oxygen or confined atmosphere. However the effect of CO2 on rice may lead to grain coloration and there is no definitive study on CO2 effects on maize, sorghum and millet during prolonged storage. There is an on-going grain storage research program undertaken by Australia with the Philippines on storage of milled rice, paddy, brown rice, maize, sorghum as well as other commodities, under particular atmospheres and controlled temperature. This program will provide valuable information on the influence of oxygen and CO2 tension in combination with temperature and water activity on grain qualities and end-uses

In any condition of storage, molds and fungi are to be controlled and destroyed since their development leads to cereals unacceptable for food and feed. Changes in processing characteristics and cooking qualities are worth studying only when grains are not contaminated.

Future studies on storage, whatever the duration, should always include a component on grain quality. Methods and instruments are available Cooperative tests as done by IRRI on rice in the 70's should be organized on maize, sorghum and millet, grains, meals and flours, for various storage periods to the benefit of food security in developing countries.

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