Available online at www.sciencedirect.com
SCIENCE DIRECT®
Food Chemistry 95 (2006) 53–57
Food Chemistry
www.elsevier.com/locate/foodchem

Storage effects on nutritional quality of commonly consumed cereals

Zia-Ur-Rehman

Food & Biotechnology Research Centre, PCSIR Laboratories Complex, Ferozepur Road, Lahore 54600, Pakistan

Received 9 August 2004; received in revised form 13 December 2004; accepted 13 December 2004

Abstract

Storage effects on nutritional quality of commonly consumed cereal grains are studied. Freshly harvested wheat, maize and rice grains were stored at 10, 25 and 45 °C for six months. A significant decrease in pH and an increase in titratable acidity was observed during storage of these three cereal grains at 25 and 45 °C. A gradual decline in moisture, total available lysine and thiamine contents was observed during storage. Total available lysine contents decreased by 6.50% and 18.5% in wheat, 14.3% and 20.7% in maize and 23.7% and 34.2% in rice during six months of storage at 25 and 45 °C, respectively. Six month's storage of rice, maize and wheat grains at 25 and 45 °C resulted in reduction of thiamine contents by 16.7% and 29.2%, 17.2% and 24.1% and 21.4% and 29.5%, respectively. About 36.4–44.4% decrease in total soluble sugars at 45 °C and 9.30–31.8% increase in total soluble sugars were observed at 10 and 25 °C during six months storage of these cereal grains. Protein and starch digestibilities of cereal grains also deceased during six months of storage at 25 and 45 °C. No significant change in nutritional quality was observed during storage of cereal grains at 10 °C.

Keywords: Cereal grains; Nutritional quality; Storage effect

1. Introduction

Wheat, maize and rice are used as sources of energy and protein in the human diet throughout the world. These cereal grains are usually stored in jute begs and earthen pots under adverse conditions of temperature and moisture in Pakistan. It has been reported in the literature that fluctuations in temperature and humidity and prolonged storage result in considerable nutrient losses (Kumar & Singh, 1984; Onigbinde & Akinycle, 1988; Shah, Rehman, Kausar, & Hussain, 2002; South, Morrison, & Nelson, 1991). Marshall and Chrastil (1992) observed that protein quality was adversely affected by storage of cereal grains at elevated temperature. The findings of Pajic, Babic, and Rodosvljevic (1992) revealed that carbohydrate composition of sweet corn was changed during storage. The moisture contents in the grains or humidity and storage temperature have also been shown to cause some changes in the acidity and pH of the cereals and cereal products (Huyghcbact & Schoner, 1999; Savich & Joldaspaeva, 1993; Zeleny & Coleman, 1938; Zhang, Wang, Zhou, & Zhang, 1997). Changes in physical characteristics have also been observed during storage of cereal grains by Kent (1974). The association between the physical changes and the changes in the chemical composition of food has made the biochemical and nutritional quality control of the stored products increasing essential. The objective of the study was to investigate the effects of storage temperature and time on the nutritional quality of different cereal grains (wheat, maize and rice).

2. Materials and methods

Freshly harvested wheat, maize and rice samples were obtained from Ayub Agriculture Research Institute,

E-mail address: pcsir@brain.net.pk (Zia-Ur-Rehman).

0308-8146/$ - see front matter
doi:10.1016/j.foodchem.2004.12.017

Faisalabad (Pakistan) and stored at 10, 25 and 45 °C for a period of six months. All these samples were free of insect infestation and no chemicals were used for preservation. About 100 g of each sample with about 11–14% moisture were placed in screw-cap plastic bottles of uniform size. Three bottles of each treatment were randomly selected at the end of each three months; contents were pooled and thoroughly mixed together for nutritional evaluation.

The samples were analyzed for pH, titratable acidity, moisture, total available lysine, soluble sugars, protein and starch digestibility before and after storage. The pH was determined on a filtrate of a 2 g ground sample (80 mesh size) in 20 ml distilled water using a glass electrode pH meter (PYE Unicam, England). The titratable acidity was expressed as sodium hydroxide required to neutralize the acids in a 100 g sample, using phenolphthalein as an indicator (AOAC, 1990). Moisture was determined using the standard method of AOAC (1990). Total soluble sugars were estimated by the phenol–sulphuric acid method of Dubois, Gilles, Hamilton, Rebers, and Smith (1956), using sucrose as the standard. The dye-binding method was used for the estimation of total available lysine in sample after hydrolyzing with 6 N HCl (Hurrell & Carpenter, 1979). The principle of the method is a quantitative binding of the azo dye, acid orange 12, by the basic groups of protein. Lysine concentration was determined by a difference method in which measurements were made with spectrophotometer (Hitachi 220S) at 475 nm, before and after blocking the lysine with propionic anhydride. In vitro protein digestibility (IVPD) was measured after digestion with pepsin–HCl solution at 37.5 °C for 24 h (Price, Butler, Rogler, & Featacrson, 1979). Starch digestibility in vitro was determined after digestion with pancreatic α amylase in 0.1 M phosphate buffer at 37 °C for 2 h (Costas, 1982). All determinations were carried out in triplicate and standard deviations (SD) were calculated according to the method of Steel and Torrie (1980). Duncan's multiple range test was used to determine significant differences ($P < 0.05$).

3. Results and discussion

Nutritional changes in cereal grains occurred, to various extents, during storage at different temperatures. The range of storage temperature included in this study, i.e., 10–45 °C, covered the atmospheric temperatures that the cereal grains would encounter in Pakistan.

It is apparent from Table 1 that there was no change at all in pH and titratable acidity of cereal grains kept at 10 °C for six months. However, significant ($P < 0.05$) changes in pH and titratable acidity occurred on storage of cereal grains at 25 and 45 °C for different time periods. A decrease in pH and an increase in titratable acidity started appearing after three months of storage at 25 °C. The mean titratable acidities of the stored rice, maize and wheat grains were 4.20, 4.50 and 3.80 mg NaOH/100 g at 25 °C and 4.83, 4.70 and 4.00 mg NaOH/100 g at 45 °C, respectively, after six months of storage. However, titratable acidities for freshly harvested rice, maize and wheat grains were 3.00, 3.25 and 2.85 mg NaOH/100 g, respectively; pH values of the freshly harvested rice, maize and wheat grains were 6.01, 6.43 and 6.57, respectively. After six months of storage, pH values became 5.50 at 25 °C and 5.00 at 45 °C for rice, 5.90 at 25 °C and 5.60 at 45 °C for maize and 5.87 at 25 °C and 5.40 at 45 °C for wheat grains. No further significant change in pH and titratable acidity value was observed after six month's storage of these cereal grains. These results are consistent with the findings of Onigbinde and Akinycle (1988), who reported an increase in acidity during storage of corn grains and

Table 1
Storage effects on pH, titratable acidity and moisture contents of cereal grains (means ± SD, triplicate samples)

Storage time (months)	Moisture (%)			pH			Acidity mg NaOH/100 g		
	10 °C	25 °C	45 °C	10 °C	25 °C	45 °C	10 °C	25 °C	45 °C
Rice									
0	11.06 ± 0.4^a	11.06 ± 0.6^a	11.06 ± 0.4^a	6.01 ± 0.1^a	6.01 ± 0.1^a	6.01 ± 0.2^a	3.0 ± 0.1^a	3.00 ± 0.3^a	3.00 ± 0.2^a
3	11.04 ± 0.5^a	10.0 ± 0.6^b	9.0 ± 0.6^b	6.01 ± 0.1^a	5.70 ± 0.1^a	5.20 ± 0.2^b	3.0 ± 0.1^a	3.80 ± 0.1^b	4.40 ± 0.2^b
6	11.02 ± 0.3^a	8.5 ± 0.5^c	7.0 ± 0.7^c	6.01 ± 0.2^a	5.50 ± 0.2^b	5.00 ± 0.2^b	3.0 ± 0.2^a	4.20 ± 0.2^b	48.3 ± 0.1^c
Maize									
0	12.50 ± 0.2^a	12.50 ± 0.3^a	12.50 ± 0.4^a	6.43 ± 0.1^a	6.43 ± 0.2^a	6.43 ± 0.2^a	3.25 ± 0.2^a	3.25 ± 0.2^a	3.25 ± 0.1^a
3	12.45 ± 0.2^a	10.70 ± 0.4^b	9.40 ± 0.4^b	6.03 ± 0.2^a	6.10 ± 0.3^a	5.80 ± 0.2^b	3.18 ± 0.1^a	4.00 ± 0.1^b	4.30 ± 0.1^b
6	12.32 ± 0.4^a	8.50 ± 0.4^c	6.40 ± 0.5^c	6.40 ± 0.2^a	5.90 ± 0.2^b	5.60 ± 0.1^c	3.00 ± 0.1^a	4.50 ± 0.1^b	4.70 ± 0.2^c
Wheat									
0	13.75 ± 0.6^a	13.75 ± 0.3^a	13.75 ± 0.4^a	6.57 ± 0.1^a	6.57 ± 0.1^a	6.57 ± 0.1^a	2.85 ± 0.1^a	2.85 ± 0.1^a	2.85 ± 0.2^a
3	13.65 ± 0.5^a	12.00 ± 0.2^b	12.70 ± 0.3^b	6.50 ± 0.1^a	6.43 ± 0.2^a	5.82 ± 0.2^b	2.80 ± 0.2^a	3.20 ± 0.2^b	3.27 ± 0.2^b
6	13.50 ± 0.4^a	11.00 ± 0.4^b	10.00 ± 0.5^c	6.50 ± 0.2^a	5.80 ± 0.1^b	5.40 ± 0.2^c	2.80 ± 0.2^a	3.80 ± 0.2^c	4.00 ± 0.2^c

Means ± SD of triplicate determinations.
Mean values within a column with different superscripts are significantly different at ($P < 0.05$).

flour. The increase in the acidity of the stored grains could be attributed to the increasing concentration of the free fatty acid and phosphate, which resulted from increased grain deterioration (Morrison, 1963). The binding of the amino group of amino acids, short chain peptides, and protein, leaving the carboxylic ends free and the presence of acid byproducts of advanced Maillard reactions are other possible causes of the increased acidity of the cereal grains stored at elevated temperatures (Fargerson, 1969; Gardner, 1979).

A gradual decline in the level of moisture took place at 25 and 45 °C while there was no change in moisture contents during storage of cereal grains at 10 °C after six month's storage (Table 1). The decrease in moisture contents became significant after three month's storage at 25 and 45 °C. Moisture contents of freshly harvested rice, maize and wheat grain were 11.06%, 12.50% and 13.75% which decreased by 23.14%, 32.00% and 20.00% at 25 °C and 36.70%, 48.80% and 27.27% at 45 °C after six months of storage. These observations are consistent with the findings of Onigbinde and Akinycle (1988).

Total available lysine contents in freshly harvested rice, maize and wheat grains were found to be 1.90%, 2.80% and 2.92%, respectively, which decreased to various extents during storage (Table 2). Total available lysine contents decreased by 23.7% and 34.2% in rice, 14.3 and 20.7% in maize and 6.50% and 18.2% in wheat grains during six months of storage at 25 and 45 °C, respectively. However, decrease in total available lysine contents was 5.26%, 7.14% and 6.50% at 10 °C during six months storage of rice, maize and wheat grains, respectively. Decrease in total available lysine at 25 and 45 °C was significant ($P < 0.05$) while it was found to be non-significant at 10 °C during six months of storage. The decrease in total available lysine during storage at different temperatures could be the result of some structural changes which inhibited proteolysis and amino acid solubility (Martin-Cabrejas et al., 1995; Sowunmi, 1981).

Significant ($P < 0.05$) changes in total soluble sugars were observed during storage of cereal grains for six months (Table 2). Total soluble sugars in rice, maize and wheat decreased by 36.4%, 44.4% and 37.2% at 45 °C during six months of storage. About 9.30–17.9% and 11.9–31.8% increases in total soluble sugars, respectively, were observed during six months storage of cereal grains at 25 and 45 °C. The increase in the soluble sugars could be the result of activity of endogenous amylases (Kramer, Guyer, & Ide, 1949) whereas the decrease in soluble sugars at 45 °C might be due to their involvement in Maillard reactions (Glass, Ponte, Christensen, & Gedder, 1959).

Thiamine contents in freshly harvested rice, maize and wheat grains were 12.0, 29.0 and 21.0 mg/100 g, respectively (Table 2). Six month's storage of rice, maize and wheat grains at 25 and 45 °C resulted in reduction of thiamine contents by 16.7% and 29.2%, 17.2% and 24.1% and 21.42% and 29.52%, respectively. However, thiamine contents in these cereal grains remained unchanged during six months of storage at 10 °C. These results are consistent with the findings of other workers who found reduction in thiamine content by 32% on storage of cowpeas for six months (Onayemi, Osibogun, & Obembe, 1986). Similar losses of thiamine were also observed by other workers during storage of chickpeas, lima beans and other cereal grains at elevated temperatures (Burr, 1973; Sudesh & Kapoor, 1994).

Protein and starch digestibilities of cereal grains were significantly ($P < 0.05$) affected at 25 and 45 °C, whereas they remained unchanged at 10 °C during storage (Table 3). Initially, protein digestibilities of rice, maize and wheat grains were 69.0%, 77.0% and 74.0%, respectively. On storage for six months at 45 °C, protein digestibility

Table 2
Storage effects on total soluble sugars, total available lysine and thiamine contents of cereal grains (means ± SD, triplicate samples)

Storage time (months)	Total soluble sugars (%)			Total available lysine (%)			Thiamine (mg/100 g)		
	10 °C	25 °C	45 °C	10 °C	25 °C	45 °C	10 °C	25 °C	45 °C
Rice									
0	4.40 ± 0.2^a	4.40 ± 0.1^a	4.40 ± 0.1^a	1.90 ± 0.1^a	1.90 ± 0.1^a	1.90 ± 0.1^a	12.0 ± 0.2^a	12.0 ± 0.1^a	12.0 ± 0.2^a
3	4.50 ± 0.3^b	5.10 ± 0.1^b	4.10 ± 0.2^b	1.80 ± 0.1^b	1.00 ± 1.0^b	1.40 ± 0.1^b	11.8 ± 0.3^a	11.0 ± 0.2^b	9.7 ± 0.2^b
6	4.65 ± 0.1^c	5.80 ± 0.2^c	2.80 ± 0.2^c	1.70 ± 0.2^c	1.45 ± 0.2^c	1.25 ± 0.1^c	11.5 ± 0.2^a	10.0 ± 0.2^c	8.5 ± 0.1^c
Maize									
0	3.60 ± 0.1^a	3.60 ± 0.2^a	3.60 ± 0.2^a	2.80 ± 0.2^a	2.80 ± 0.2^a	2.80 ± 0.2^a	29.0 ± 0.4^a	29.0 ± 0.5^a	29.0 ± 0.4^a
3	3.90 ± 0.2^b	4.00 ± 0.2^b	3.00 ± 0.2^b	2.70 ± 0.1^b	2.50 ± 0.2^b	2.45 ± 0.2^b	28.8 ± 0.3^a	26.0 ± 0.3^b	24.0 ± 0.4^b
6	4.15 ± 0.2^c	4.35 ± 0.2^c	2.00 ± 0.3^c	2.60 ± 0.2^c	2.40 ± 0.2^c	2.22 ± 0.2^c	28.7 ± 0.2^a	24.0 ± 0.3^c	22.0 ± 0.3^c
Wheat									
0	3.44 ± 0.2^a	3.44 ± 0.3^a	3.44 ± 0.4^a	2.92 ± 0.2^a	2.92 ± 0.2^a	2.92 ± 0.1^a	21.0 ± 0.2^a	21.0 ± 0.3^a	21.0 ± 0.3^a
3	3.58 ± 0.2^b	3.68 ± 0.1^b	2.83 ± 0.1^b	2.82 ± 0.2^b	2.64 ± 0.1^b	2.48 ± 0.1^b	20.7 ± 0.3^a	18.0 ± 0.3^b	16.5 ± 0.3^b
6	3.76 ± 0.3^c	3.85 ± 0.1^c	2.16 ± 0.2^c	2.73 ± 0.1^c	2.39 ± 0.1^c	2.26 ± 0.2^c	20.5 ± 0.3^b	16.5 ± 0.2^c	14.8 ± 0.3^c

Means ± SD of triplicate determinations.
Mean values within a column with different superscripts are significantly different at ($P < 0.05$).

Table 3
Storage effects on protein and starch digestibilities of cereal grains (means ± SD, triplicate samples)

Storage time (months)	Protein digestibility (%)			Starch digestibility (%)		
	10 °C	25 °C	45 °C	10 °C	25 °C	45 °C
Rice						
0	69.0[a]	69.0[a]	69.0[a]	70.0[a]	70.0[a]	70.0[a]
3	69.0[a]	65.0[b]	63.0[b]	70.0[a]	64.0[b]	62.0[b]
6	69.0[a]	63.0[c]	60.0[c]	70.0[a]	61.0[c]	57.0[c]
Maize						
0	77.0[a]	77.0[a]	77.0[a]	58.0[a]	58.0[a]	58.0[a]
3	76.8[a]	72.5[b]	71.0[b]	57.9[a]	55.0[b]	52.0[b]
6	76.5[a]	70.0[b]	65.0[c]	57.5[a]	50.0[c]	46.0[c]
Wheat						
0	74.0[a]	74.0[a]	74.0[a]	62.0[a]	62.0[a]	62.0[a]
3	73.9[a]	70.0[b]	67.0[b]	62.0[a]	58.0[b]	56.0[b]
6	73.5[a]	67.0[b]	61.0[c]	61.5[a]	55.0[c]	51.0[c]

Means ± SD of triplicate determinations.
Mean values within a column with different superscripts are significantly different at ($P < 0.05$).

decreased by 13.0%, 15.6% and 17.6% in rice, maize and wheat grains, respectively. However, decreases in protein digestibilities were only 8.69%, 9.09% and 9.45% after six months storage of rice, maize and wheat grains, respectively, at 25 °C. Similarly, starch digestibility values for freshly harvested rice, maize and wheat grains were 70.0%, 58.0% and 62.0%, respectively (Table 3). Decreases in starch digestibilities were 17.1%, 20.7% and 17.7% at 45 °C and 12.9%, 13.8% and 11.3% at 25 °C after six months storage of rice, maize and wheat grains, respectively. These results are consistent with the findings of earlier workers who found a distinct decrease in protein digestibility of wheat, maize and cowpeas during storage (Burr, 1973; Onayemi et al., 1986). Decreases in protein and starch digestibilities could be the result of Maillard reactions, during which free amino groups of protein and carbonyl groups of reducing sugars form complex intermediate compounds by interacting with each other during storage. These complex compounds might have inhibited the activity of proteolytic and amylolytic enzymes which ultimately caused distinct reductions in protein and starch digestibilities (Marshall & Chrastil, 1992).

4. Conclusion

Nutritional quality of cereal gains was adversely affected as a result of storage at elevated temperatures. Protein and starch digestibilities of cereal grains decreased to various extents on storage at 25 and 45 °C for six months. Significant losses of lysine and thiamine occurred on storage of cereal grains at 25 and 45 °C. At 45 °C, losses in soluble sugars were also observed during six month's storage of cereal grains. In view of these facts, it is suggested that cereal grains (wheat, maize and rice) should not be stored above 25 °C in order to minimize nutrient losses during storage.

References

Association of Official Analytical Chemists (AOAC). (1990). *Official methods of analysis* (14th ed.). Washington DC, USA: Association of Official Analytical Chemists.

Burr, H. K. (1973). Effect of storage on cooking qualities, processing and nutritive value of beans. In W. G. Jaffe (Ed.), *Nutritional aspects of common beans and other legume seeds as animal and human foods*. Riberrao Preto Brazi; Arch Latiaoameri Nutr.

Costas, G. B. (1982). Physical characteristics, enzymatic digestibility and structure of chemically modified pea and waxy maize starches. *Journal of Agricultural and Food Chemistry, 30*, 925–930.

Dubois, M. M., Gilles, K. A., Hamilton, J. K., Rebers, P. A., & Smith, F. (1956). Colorimetric method for determination of sugars and related substances. *Analytical Chemistry, 26*, 350–355.

Fargerson, S. I. (1969). Thermal degradation of carbohydrate: a review. *Journal of Agricultural and Food Chemistry, 17*, 747–750.

Gardner, H. W. (1979). Lipid hydroperoxide reactivity with protein and amino acids: a review. *Journal of Agricultural and Food Chemistry, 27*, 220–228.

Glass, R. L., Ponte, J. G., Jr, Christensen, C. M., & Gedder, W. F. (1959). Grain storage studies XXVIII. The influence of tenperature and moisture level on the behaviour of wheat stored in air or nitrogen. *Cereal Chemistry, 36*, 341–347.

Hurrell, R. F., & Carpenter, K. J. (1979). An approach to the rapid measurement of reactive lysine in foods by dye binding. *Proceedings of the Nutrition Society, 35*, 23A–24A.

Huyghcbact, G., & Schoner, F. J. (1999). Influence of storage and addition of enzyme on metabolizable energy content of wheat. *Arch Gefluegelkd, 63*, 13–20.

Kent, N. L. (1974). *Technology of cereals*. Oxford, UK: Pergarrion Press.

Kramer, A., Guyer, R. B., & Ide, L. E. (1949). Factors affecting the objective and organoleptic evaluation of quality of sweet corn. *Journal of the American Society for Horticultural Science, 54*, 342–346.

Kumar, R., & Singh, R. (1984). Levels of free sugars, intermediate metabolites and enzymes of sucrose–starch conversion in develop-

ing corn grains. *Journal of Agricultural and Food Chemistry, 32*, 806–808.
Marshall, W. E., & Chrastil, J. (1992). Interaction of food protein and starch. In B. J. F. Hudson (Ed.), *Biochemistry of food proteins*. London, UK: Elsevier Applied Science.
Martin-Cabrejas, M. A., Esteban, R. M., Waldron, K., Mains, G., Grant, G., Barboez, S., et al. (1995). Hard to cook phenomenon in beans. Changes in anti nutrient factors and nitrogenous compounds during storage. *Journal of the Science of Food and Agriculture, 69*, 429–435.
Morrison, W. R. (1963). The free fatty acid content of some corn flours. *Science of Food and Agriculture, 14*, 870–873.
Onayemi, O., Osibogun, O. A., & Obembe, O. (1986). Effect of different storage and cooking methods on some biochemical, nutritional and sensory characteristics of cowpeas (V. Unguiculata L. Walp). *Journal of Food Science, 51*, 153–156.
Onigbinde, A. O., & Akinycle, I. O. (1988). Biochemical and nutritional changes in corn (*Zea mays*) during storage at three temperatures. *Journal of Food Science, 53*, 117–120.
Pajic, Z., Babic, M., & Rodosvljevic, M. (1992). Effect of environmental factors on changes in carbohydrate composition of sweet corn. *Genetika, 24*, 49–56.
Price, M. L., Butler, L. G., Rogler, J. C., & Featacrson, W. R. (1979). Overcoming the nutritionally harmful effects of tannin in sorghum grains by treatment with inexpensive chemical. *Journal of Agricultural and Food Chemistry, 27*, 441–444.
Savich, I. M., & Joldaspaeva, G. M. (1993). Digestibility of corn proteins. *Fiziol Biokhm Kult Rast, 25*, 452–458.
Shah, W. H., Rehman, Z. U., Kausar, T., & Hussain, A. (2002). Storage of wheat with ears. *Pakistan Journal of Scientific and Industrial Research, 17*, 206–209.
South, J. B., Morrison, W. R., & Nelson, O. E. (1991). A relationship between the amylose and lipid contents of starches from various mutants for amylose contents in maize. *Journal of Cereal Science, 14*, 267–278.
Sowunmi, E. Q. (1981). Biochemical and nutritional changes in corn and cowpea. PhD thesis, University of Fabodan, Nigeria.
Steel, R. G. D., & Torrie, J. H. (1980). *Principles and procedures of statistics*. London: McGraw-Hill.
Sudesh, J., & Kapoor, A. C. (1994). Vitamin contents of cereal grains as affected by storage and insect infestation. *Plant Foods Human Nutrition, 46*, 237–243.
Zeleny, L., & Coleman, D. A. (1938). Acidity in cereals and cereal products, its determination and significance. *Cereal Chemistry, 15*, 580–583.
Zhang, J., Wang, T., Zhou, C., & Zhang, C. (1997). Changes of wheat protein stored under different conditions. *Zhengzhou Lianggh Xueyuan Xuchao, 18*, 72–76.