# MOISTURE EQUILIBRIUM OF BULGUR[1]

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**ABSTRACT**

The equilibrium moisture behavior of four different samples of bulgur was determined for a range of temperature and humidity. The bulgurs represented combinations of such parameters of interest as red *vs.* white wheat, atmospheric *vs.* pressure cooking, and whole *vs.* cracked kernels. The temperatures used were 65°, 78°, and 90°F. and the range of relative humidities (r.h.) was from about 10 to 100%. Mold appeared in all samples at r.h. values of 84% and above in 4 to 46 days, depending upon temperature and r.h. At a given r.h., the equilibrium moisture content decreased with increasing temperature, but the rate of change is lower at higher temperatures. After equilibration by desorption the bulgur was at higher moisture content than after equilibration by absorption. Neither the type of wheat from which it is made, the cooking process, nor the state of subdivision influenced the equilibrium moisture content of bulgur to any great extent.

Since 1961 bulgur has been available for distribution in the Foods for Peace Program, and its use in this program has been steadily increasing. Therefore, a very large proportion of the bulgur produced in this country today is being widely distributed overseas to areas where it may be transported and stored under a wide range of temperature and humidity. When properly handled, bulgur is a very stable food, but poor storage conditions can, of course, reduce its stability. The

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importance of moisture content to the stability of foods makes it desirable to determine how the temperature and humidity of the environment influence the moisture content of bulgur. This is the objective of the present report.

## Materials and Methods

*Bulgur.* Batches of whole-kernel bulgur were produced commercially by two different processors from a single uniform lot of hard red winter wheat. One process used pressure cooking; the other used cooking at substantially atmospheric pressure. A batch of whole-kernel bulgur from a uniform lot of white wheat (club type) was also prepared by the processor, who used atmospheric pressure cooking.

Samples of each of the three batches of bulgur were ground in a Hobart Coffee Mill[3] at a coarse setting and screened to remove material larger than 18-mesh per in. and finer than 30-mesh per in. The particle size distribution of the screened product meets the purchase specifications established for bulgur going into the Food for Peace Program. For comparison, a sample of the atmospheric-cooked bulgur from hard red winter wheat was left in whole kernels. The samples were coded as follows:

| *Code* | *Wheat* | *Cooking* |
|---|---|---|
| CRP | Cracked, red | Above atm. pressure |
| CWA | Cracked, white | At atm. pressure |
| CRA | Cracked, red | At atm. pressure |
| WRA | Whole-kernel, red | At atm. pressure |

The WRA sample was from the same batch as the CRA, but not cracked.

Proximate analyses (1) for these bulgurs are presented in Table I.

TABLE I
PROXIMATE ANALYSIS ON BULGUR SAMPLES
(All values are on a 14% moisture basis except for moisture)

| BULGUR SAMPLE | MOISTURE | PROTEIN (N × 5.7) | ETHER EXTRACT | CRUDE FIBER | ASH |
|---|---|---|---|---|---|
| | % | % | % | % | % |
| CRP | 8.90 | 9.2 | 1.5 | 1.6 | 1.40 |
| CWA | 8.89 | 8.4 | 1.3 | 1.3 | 1.30 |
| CRA | 8.03 | 9.1 | 1.4 | 1.6 | 1.43 |
| WRA | 8.12 | 9.5 | 1.5 | 1.8 | 1.44 |

*Apparatus.* The equipment for equilibrating the samples at several humidity conditions was essentially the same as used by Houston (2). An approximately 5-g. subsample of bulgur was weighed accurately

[3] Reference to a company or product name does not imply approval or recommendation of the product by the U.S. Department of Agriculture to the exclusion of others that may be suitable.

into a small wire-mesh basket and suspended in jars over saturated solutions of various salts which were selected to produce a wide range of relative humidities (r.h.). The salts and the r.h. over a saturated solution at 65°, 78°, and 90°F. were as follows: Lithium chloride (11.1, 11.1, 11.1), magnesium chloride hexahydrate (33.2, 32.7, 32.2), sodium dichromate dihydrate (55.3, 53.4, 51.5), sodium chloride (75.7, 75.4, 75.2), ammonium dihydrogen phosphate (93.5, 92.6, 91.7) (3), and potassium chloride (85.1, 84.7, 83.9) (4). Water was used to provide an atmosphere approaching 100% r.h. The jars were held in constant-temperature rooms at 65°, 78°, and 90°F. and periodically weighed in the same room on an analytical balance. The construction of the apparatus allowed weighing without removal of the sample from the conditioning atmosphere. Weighings continued until constant weight was reached, until changes corresponded to less than 0.05% moisture in a week, or until obvious mold developed. When mold appeared equilibrium could not be accurately established, and values are only presumptive. Moisture contents were determined from the original moisture content and the weight change.

Some experiments were conducted in which potassium sorbate was applied to the bulgur at 200, 400, and 600 p.p.m. These applications did not prevent nor delay the onset of mold at the higher humidities as judged by comparison with results obtained with untreated samples.

## Results and Discussion

Equilibrium moisture contents were determined for the four bulgurs at three temperatures and at the selected relative humidities. However, direct comparisons among the data so obtained are difficult, because relative humidities above some of the salt solutions change with temperature. Therefore, equilibrium moisture contents for all the samples for 10% increments of relative humidity obtained from the data by straight-line interpolation (and extrapolation to 10% r.h.) are presented in Table II.

Observations made during the progress of the experiments indicated that higher temperatures and the cracked form of bulgur speeded attainment of equilibrium. Mold appeared on the samples at the three highest humidities (about 84% r.h. and above). The first visible mold appeared in only 4 days at 90°F. and 100% r.h., but as long as 46 days was required at 65°F. and about 85% r.h. No mold appeared in samples at r.h. values below about 75%. This would indicate that the minimum moisture content for mold growth probably lies in the range of 13 to 17%. The upper limit for moisture content in the Federal

TABLE II
INTERPOLATED EQUILIBRIUM MOISTURE CONTENTS

| Bulgur Sample | Relative Humidity (%) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80[a] | 90[b] | 100[c] |
| | % | % | % | % | % | % | % | % | % | % |
| | | | | | 65°F. | | | | | |
| CRP | 5.8 | 7.1 | 8.4 | 9.4 | 10.4 | 11.6 | 13.0 | 15.6 | 21.3 | . . . |
| CWA | 5.9 | 7.1 | 8.4 | 9.4 | 10.2 | 11.4 | 12.9 | 15.4 | 21.0 | 28.8 |
| CRA | 5.6 | 6.8 | 7.9 | 8.9 | 9.8 | 11.1 | 12.7 | 15.4 | 21.8 | 32.7 |
| WRA | 5.4 | 6.5 | 7.6 | 8.6 | 9.5 | 10.8 | 12.4 | 15.2 | 21.5 | . . . |
| | | | | | 78°F. | | | | | |
| CRP | 5.1 | 6.5 | 7.9 | 8.9 | 9.7 | 10.8 | 12.4 | 14.7 | 19.6 | 28.6 |
| CWA | 5.4 | 6.7 | 8.0 | 9.0 | 9.7 | 10.8 | 12.4 | 14.6 | 19.7 | 24.8 |
| CRA | 5.1 | 6.3 | 7.6 | 8.5 | 9.2 | 10.4 | 12.3 | 14.7 | 19.9 | 28.8 |
| WRA | 5.1 | 6.3 | 7.6 | 8.5 | 9.2 | 10.4 | 12.3 | 14.8 | 20.1 | . . . |
| | | | | | 90°F. | | | | | |
| CRP | 5.0 | 6.5 | 7.9 | 9.0 | 9.6 | 10.7 | 12.3 | 14.6 | 20.2 | . . . |
| CWA | 4.9 | 6.4 | 7.8 | 8.8 | 9.3 | 10.4 | 12.2 | 14.5 | 19.7 | 29.0 |
| CRA | 4.9 | 6.1 | 7.4 | 8.5 | 8.9 | 10.1 | 12.2 | 14.6 | 20.0 | . . . |
| WRA | 4.9 | 6.1 | 7.4 | 8.5 | 9.0 | 10.2 | 12.2 | 14.6 | 19.9 | . . . |

[a] Mold visible in 14 to 46 days at r.h. values 83.9 to 85.1, but equilibrium moisture appeared to be reached before molding occurred.
[b] Mold visible in 7 to 21 days at r.h. values 91.7 to 93.5 and before equilibrium was attained. Influence of mold on equilibrium moisture uncertain but appears to be small.
[c] Mold visible in 4 to 17 days. Weight changes were very erratic, and equilibrium moisture could be roughly estimated only for certain samples.

Standards for many grains lies in this range. Mold growth is an obvious deterioration that is influenced by temperature and moisture content, but other less obvious chemical changes may also be influenced, although perhaps to different degrees. On the basis of mold growth alone these data point out a hazard to be considered whenever bulgur is shipped or stored under high humidity conditions, particularly when the temperature is high.

The data in Table II show a decrease in equilibrium moisture content with increasing temperature, as is common for many natural products. The magnitude of the decrease is smaller as temperature increases; for example, for an almost equal temperature interval the differences between 65° and 78°F. are somewhat larger than those between 78° and 90°F.

Neither the type of wheat, the cooking process, nor the state of subdivision very greatly influenced the equilibrium moisture contents of the bulgurs at a given temperature and relative humidity. However, some trends of unknown significance, based on very consistent differences of small magnitude, appear when the data from 10 to 80% r.h. are considered. The pressure-cooked bulgur consistently had a little higher equilibrium moisture content than the atmospheric-cooked samples (CRP *vs.* CRA) up to 70% r.h.; above that point the differences diminished somewhat. A similar difference is observed between red and white wheat (CWA *vs.* CRA). In this case the white wheat attains the higher moisture content. Comparison of cracked and whole form (CRA *vs.* WRA) reveals that the cracked form is consistently higher in moisture content than the whole-kernel form only at 65°F.

Because the initial moisture contents of the bulgurs were in the range of 8 to 9% (Table I), the equilibrium moisture contents were approached from lower levels for all r.h. values except the two lowest. We were interested in knowing whether the same moisture levels would be attained when bulgurs started equilibration from higher initial moisture levels. Therefore, samples were equilibrated at 90°F. over potassium chloride (r.h. = 83.9%) long enough to attain moisture levels in the range of 15–16%; then they were transferred to atmospheres at the four lowest r.h. values (11.1, 32.2, 51.5, 75.2%) and again allowed to attain equilibrium. Other samples with starting moisture contents in the 8–9% range were exposed simutaneously to the same r.h. value. Results of this experiment are shown in Fig. 1.

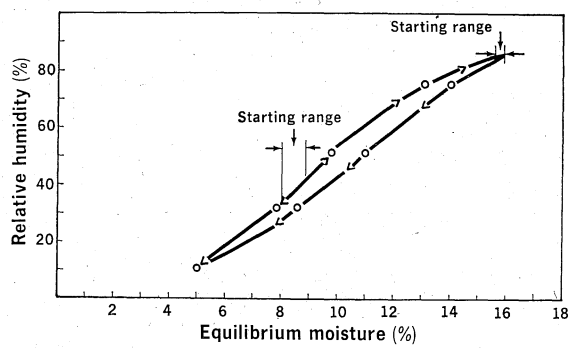


Fig. 1. Equilibrium moisture content of bulgur by absorption and desorption.

There was clearly a difference in final moisture content, depending upon whether equilibrium was approached from a higher or lower moisture content — desorption or absorption, respectively. Differences at 75.2% r.h. ranged from 0.8 to 1.1% (1.0% average) and at 51.5% r.h., from 1.1 to 1.5% (1.3% average). At 32.2% r.h. the initial moisture level of the lower-moisture sample was very nearly equal to the equilibrium value. In this case the differences were smaller and in the range of 0.4 to 0.9% (0.7% average). At the lowest r.h. value used, differences in final moisture content were insignificant. In this case the approach to equilibrium was from the same direction, although the moisture range to be traversed differed substantially in the two cases (about 3% as against about 10%).

The differences in moisture content for bulgur equilibrated by absorption and desorption at 90°F. and at 51.5% and 75.2% r.h. compare fairly closely with those for wheat interpolated to comparable conditions from observations by Hubbard *et al.* (5).

Equilibrium moisture values for wheat, rice, and several rice products at storage temperatures around 77°F. are available from the literature. For comparison with such values the data for bulgur at 78°F. were averaged for the four samples, and the equilibrium moisture contents obtained are shown in Table III, together with those of the other products, for a range of relative humidities.

TABLE III

COMPARISON OF EQUILIBRIUM MOISTURE CONTENTS OF BULGUR WITH THOSE OF OTHER GRAIN PRODUCTS AT VARIOUS RELATIVE HUMIDITIES
(Temperatures: bulgur, 78°F.; rice, 77°F.; wheat, 77–82.4°F.)

| R.H. | Moisture Contents | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Bulgur | Rice | | | | | | Wheat | |
| | | Par-boiled [a] | Quick Cooking [a] | Brown [b] | White [c] | Rough [d] | Rough [e] | HRW [f] | White [f] |
| % | % | % | % | % | % | % | % | % | % |
| 10 | 5.2 | 5.9 | 5.5 | 6.2 | 5.2 | 4.4 | . . | 5.8 | 6.2 |
| 20 | 6.5 | 8.0 | 7.4 | 8.0 | 7.6 | 6.5 | 7.6 | 7.2 | 7.6 |
| 30 | 7.8 | 9.5 | 8.9 | 9.5 | 9.2 | 7.9 | 9.0 | 8.5 | 8.6 |
| 40 | 8.8 | 10.9 | 9.7 | 10.9 | 10.5 | 9.1 | 10.2 | 9.2 | 9.0 |
| 50 | 9.5 | 12.2 | 10.5 | 12.3 | 12.0 | 10.4 | 11.3 | 11.9 | 11.2 |
| 60 | 10.6 | 13.3 | 11.5 | 13.5 | 13.4 | 11.8 | 12.6 | 12.5 | 11.8 |
| 70 | 12.4 | 14.1 | 13.1 | 14.8 | 14.8 | 13.2 | 13.8 | 13.9 | 13.9 |
| 80 | 14.7 | 15.2 | 15.4 | 16.2 | 16.4 | 14.8 | 15.3 | 17.4 | 17.1 |
| 90 | 19.8 | 19.1 | 20.1 | 19.1 | 18.8 | 17.6 | 18.1 | 20.1 | 21.2 |
| 100 | 27.4 | . . . | . . . | . . . | . . . | . . . | . . . | 25.3 | 26.3 |

[a] Data from ref. 7.
[b] Data from ref. 3.
[c] Data from ref. 8 as quoted in ref. 7.
[d] Data from ref. 8 as quoted in ref. 3.
[e] Data from ref. 9 as quoted in ref. 3.
[f] Data from ref. 9 converted to wet basis and interpolated. Average of 11 samples of HRW and three White wheats.

With few exceptions (one sample of rough rice at lower r.h. and white rice at 10% r.h.), bulgur shows a lower equilibrium moisture content than any of the other products at the same r.h. values up to 80% r.h. Therefore, to the degree that lower moisture content decreases deteriorative processes or reduces molding, bulgur's lower moisture level should favorably influence its stability over these other cereals.

The highest moisture content for bulgur that is allowed without penalty under the present specifications for government procurement is 11.5%. From the data we have presented, bulgur at this moisture level would be in equilibrium with an atmosphere slightly above 60% r.h. at 65°F., about 65% r.h. at 78°F., and slightly above 65% r.h at 90°F. Therefore, humidities in excess of 60% r.h. would be required to cause moisture pick-up in bulgur having this initial moisture content.

The moisture content of bulgur at a particular r.h. value is clearly influenced by previous history, i.e., whether it is reached by absorption or desorption of moisture. Equilibria reached at the same atmospheric r.h. by absorption are lower than those reached by desorption. Those holding bulgur should be cautious against allowing the moisture content to reach a level where reduction of moisture content is required, for then a moisture content in equilibrium with a given r.h. value will be as much as 1.5% higher. In other words, to obtain the same moisture content by desorption as by absorption, an atmosphere of considerably lower r.h. would be required, as is normally the case in artificial drying.

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