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The Equilibrium Moisture Content of Tung Fruit and Its Components at Different Relative Humidities

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THE drying of tung fruit and seeds so that they can be milled or stored with safety has been an important problem of the tung oil industry. The tung fruit falling from the trees contains about 65% moisture and will heat, mold, and sprout if stored before being dried to about 25% moisture. Since the hulls contain more than half of the moisture present in the whole fruit, their removal before drying or storage is desirable to minimize the heat required for drying and to reduce the space required for storage. However it has been found that the moist, broken seed produced by the usual commercial hulling operation will develop free fatty acids rapidly and heat spontaneously unless dried to about 10% moisture.

Tung fruit and its products tend to assume a moisture content in equilibrium with that of the surrounding atmosphere, hence knowledge of their equilibrium moisture content at different relative humidities is of considerable importance in the drying and storage of these products. Also, in the spontaneous heating of ground hulls and press cake, equilibrium moisture contents are important because it is believed by certain workers in this field that the relative humidity of the interstitial air determines whether mold growth and heating takes place or not, rather than the moisture content of the material *per se*.

Holmes and Pack (1) determined the equilibrium moisture contents of tung seeds and kernels at different relative humidities for two different temperatures, but the temperatures could not be controlled accurately.

The following experimental work was carried out by placing samples of the test materials in desiccators containing saturated solutions of different salts and storing them in a room held constant at 25° C., using essentially the same equipment and procedures described by Karon and co-workers (2, 3) in determining the hygroscopic equilibrium of rice and peanuts. The nine salts used and the relative humidities maintained by their saturated solutions at 25° C. are given at the top of Table I. These values are taken from Technical Report No. 40 of the American Paper and Pulp Association (4).

Outer hulls, inner hulls, shells, kernels, intact seeds, press cake, and whole fruit were used in these experiments. A batch of fresh tung fruit was divided by hand into outer hulls, inner hulls, shells, and kernels. The seeds (composed of kernel plus shell) and whole fruit were from the same batch of fruit after it had been dried to the equilibrium moisture content at the prevailing humidity of the laboratory. Samples of each material were placed in trays with wire screen false bottoms, made to fit the desiccators and divided radially into four compartments. The experiments on the outer hulls, inner hulls, shells, and kernels were carried on simultaneously in the same desiccators; those on the seeds and press cake were conducted simultaneously; but those on the whole fruit were made alone.

Before placing the materials in the desiccators, the hulls, shells, and press cake were ground in a Wiley mill to pass a 0.25-inch screen. Because tung oil oxidizes rapidly and the materials had to be stored for several weeks, the kernels, seeds, and fruit (all products high in oil content) were used without grinding to minimize oxidization.

In addition to the material contained in trays in the desiccators, small baskets made of very fine screens were filled with the same materials (except whole fruit), placed in the desiccators, and weighed every few days. From the changes in weight and the original moisture content of samples, the approximate moisture content could be calculated as a check on the establishment of equilibrium.

For the determination of moisture in the hull, shell, and press cake, portions of about five grams each were rapidly transferred to a previously weighed moisture dish. The dish was immediately covered and weighed, then with the cover removed was dried to

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TABLE I

Moisture Contents of Tung Fruit and Its Components at Different Relative Humidities

Conditioning Period, days	Relative Humidity of Conditioning Atmosphere, %								
	11.1 (LiCl)	22.5 ($KC_2H_3O_2$)	32.5 ($MgCl_2$)	43.7 (K_2CO_3)	53.3 ($Na_2Cr_2O_7$)	64.4 ($NaNO_2$)	75.4 (NaCl)	86.4 (K_2CrO_4)	92.5 ($NH_4H_2PO_4$)
					Ground Outer Hulls				
0	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6
5	9.8	14.3	16.1	17.7	18.7	18.8	19.4	21.2	21.4
9	7.9	12.3	14.4	16.5	17.8	18.4	19.4	21.9	22.8
16	7.1	11.3	13.1	15.4	17.2	18.2	20.0	22.5	24.5
27	5.8	10.4	12.1	13.9	15.9	17.5	19.6	22.3	25.7
41	5.0	9.5	11.3	13.2	15.3	17.1	19.2	22.8	26.6
62	4.9	9.3	11.3	13.4	14.6	16.4	19.6	23.0	27.6
					Ground Inner Hulls				
0	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1
5	6.6	9.6	11.0	12.3	13.2	13.5	14.4	16.1	16.4
9	5.2	8.3	10.0	11.6	12.8	13.3	14.5	16.7	17.7
16	4.4	7.5	9.2	11.1	12.3	13.0	14.9	17.4	19.6
27	3.7	7.2	8.6	10.3	11.4	13.0	14.7	17.3	20.9
41	3.2	6.6	7.9	9.8	11.1	12.7	14.4	17.8	21.5
62	3.0	6.5	8.0	9.8	10.8	12.1	14.8	18.0	22.3
					Ground Shells				
0	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2
5	6.8	9.8	10.6	11.3	11.6	11.8	12.1	12.8	12.8
9	4.9	8.5	9.8	10.8	11.3	11.7	12.2	12.9	13.2
16	4.3	7.9	9.4	10.7	11.5	11.8	12.6	13.3	14.0
27	3.3	7.2	8.7	10.0	10.9	11.6	12.4	13.1	14.1
41	2.8	6.5	8.3	9.5	10.6	11.5	12.3	13.1	14.2
62	2.5	6.4	8.1	9.6	10.4	11.2	12.4	13.2	14.3
					Whole Tung Kernels				
0	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4
13	1.9	—	3.4	3.9	4.6	4.9	5.9	6.9	7.8
19	1.6	2.6	3.1	3.8	4.4	4.6	5.5	7.7	7.9
27	1.5	2.8	3.1	3.4	4.0	4.8	5.3	7.4	8.8
41	1.2	2.6	3.7	3.4	3.9	5.6	5.7	6.9	8.8
69	—	2.3	3.0	3.2	3.9	4.2	5.5	7.2	9.4
[a]69	1.8	3.1	3.5	4.0	4.4	5.4	6.1	8.1	11.0
					Ground Press Cake				
0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
5	6.0	7.0	7.6	8.1	8.6	9.0	9.7	10.4	10.9
10	5.1	6.4	7.0	7.7	8.3	9.0	10.0	11.2	12.3
18	4.1	5.5	6.2	6.8	7.4	8.3	9.8	11.0	13.2
24	3.9	5.2	6.0	6.7	7.4	8.2	9.9	11.4	14.1
31	3.9	5.3	6.1	6.8	7.4	8.3	10.1	12.3	16.1
38	3.9	5.3	6.0	6.7	7.4	8.3	10.1	12.3	16.1
45	3.9	5.2	6.1	6.8	7.4	8.4	10.3	12.6	16.5
					Whole Seeds				
0	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1
5	5.0	6.3	6.7	7.4	7.7	8.0	8.4	8.7	9.1
10	3.9	5.4	6.0	7.0	7.4	7.9	8.6	9.1	9.7
18	3.1	4.3	5.5	6.4	6.6	7.7	8.2	8.6	9.9
24	3.0	4.4	5.3	6.1	6.8	7.4	8.2	—	11.4
31	3.0	4.4	4.9	6.0	6.4	7.2	8.0	9.7	11.1
38	3.0	4.2	5.0	6.1	6.7	7.4	8.0	9.1	10.4
45	2.8	4.0	4.9	6.1	7.1	7.3	8.2	9.4	11.3
[a]45	3.3	4.6	5.5	6.5	7.2	7.8	8.7	10.0	11.9
					Whole Fruit				
0	10.2	10.3	10.0	9.9	9.9	10.0	9.6	9.4	9.7
8	6.2	8.1	8.7	9.6	10.2	11.0	11.6	12.8	13.8
15	5.6	7.7	8.5	9.5	10.2	11.3	12.1	13.5	15.2
22	5.2	7.2	8.3	9.4	10.1	11.2	12.2	13.7	15.9
29	5.2	7.2	8.2	9.3	10.2	11.3	12.4	14.0	16.5
[a]39	5.3	7.3	8.2	9.5	10.4	11.4	12.4	14.1	17.2

[a] Final moistures determined in vacuum oven on ground sample. See text.

constant weight (2 to 3 hours) in a mechanical convection oven at 101°.

The amounts of seeds and kernels in the desiccators were not large enough to permit using more than about six seeds or kernels at a sampling. Since it was not practical to grind and recover such small samples in the mills available, moisture was determined by drying whole seeds and kernels to a constant weight (6-8 hours). At the end of the experiment the remaining seeds and kernels were rapidly ground through a closed Wiley mill, the sample mixed in a closed jar, and approximately 5-gram portions were transferred to a previously weighed moisture dish. The samples were dried for 2.5 hours at 101-103° in a vacuum oven to minimize oxidation of the oil.

In the case of the whole fruit, the desiccator trays were filled with 15-20 fruit and weighed. The trays and contents were weighed at intervals until equilibrium was attained as indicated by constant weight. The fruit was then ground in a closed Wiley mill and moistures determined in a vacuum oven as described for kernels and seeds. Moistures for other periods of storage were calculated from the changes in weight.

The moisture content of the various products after storage in the desiccators for different periods is shown in Table I. The equilibrium moisture contents were plotted against relative humidity and smooth curves passed through the points. These curves are shown in Figure I. The moisture contents shown in the second and third lines for outer hull, inner hulls, shell, and press cake were calculated from the basket weights. The other values for these components were determined by oven methods described above. For at least the last two weeks before the experiments were discontinued, the moisture contents of the hulls,

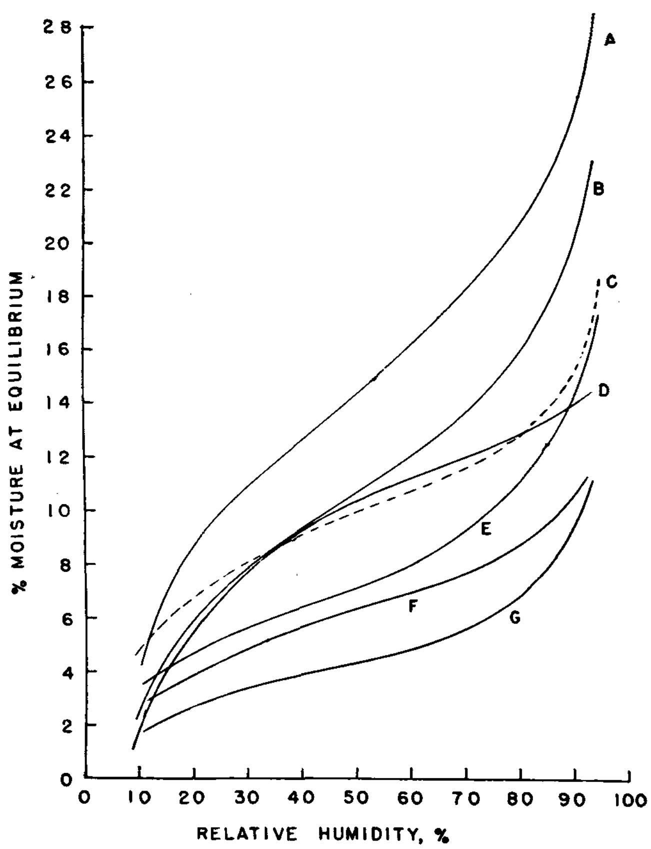

FIG. 1. The effect of relative humidity on equilibrium moisture content of (A) outer hull; (B) inner hull; (C) whole fruit; (D) shell; (E) press cake; (F) seed; (G) kernels.

shells, and press cake were determined in duplicate, as were the final moisture contents of the seeds, kernels, and whole fruit.

Samples maintained in the desiccators at 86.4 and 92.5% relative humidities molded. Because of the mold growth these samples did not come to equilibrium at the end of the experimental period since the mold mycelia have higher moisture contents than the substrates. Except for the products from these two desiccators the experiments were continued until the moisture content did not change more than 0.1% in a period of one week, or until the moistures began to vary slightly up and down about the mean.

The average relative humidity of the atmosphere in the tung area is about 75%. The equilibrium moisture contents of fruit, kernels, and seeds in contact with the atmosphere at 75% relative humidity are approximately 12.4, 6.1, and 8.2% respectively. Therefore if these products are to be held in contact with the atmosphere for any length of time, there is no need of drying them below these moisture levels.

Commercial hulls contain practically all the outer and inner hulls, but the proportion of shell varies from nearly zero to about 70% of the shell in the fruit, hence the equilibrium moisture content of commercial hulls will differ from that of the hand-separated hulls depending upon the proportion of shell included with the hulls.

The component composition of the fruit used in these studies on a dry weight basis was as follows: outer hull, 38.6; inner hull, 7.0; shell, 21.1; and kernels, 33.3%, respectively. The equilibrium moisture content at 75.4% relative humidity of the components of the fruit used in these studies was as follows: outer hulls, 19.3; inner hull, 14.7; shell, 12.3; and kernels, 6.1%, respectively.

With no shell included with the hulls, the equilibrium moisture content of commercial hulls would be the weighted average of the values for the outer and inner hulls or 18.6%. With 70% of the shell included with the hulls, the equilibrium moisture content of the commercial hulls would be the weighted average of the values for outer and inner hulls and 70% of that for shell, or 17.1%. Therefore in storing commercial hulls in contact with the atmosphere, there is no need of drying them below 17% moisture.

The equilibrium moisture content of the press cake at 75.4% relative humidity is 10.3%.

Summary

The equilibrium moisture contents at 25° C. were determined for the whole tung fruit, the outer hull, the inner hull, shell, kernels, and seed of the fruit, and on the cake from continuous screw presses at nine different relative humidities. The relative humidities were maintained by enclosing saturated solutions of different salts in desiccators in a room maintained at constant temperature.

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