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Relationship Between Kernel Moisture Content and Water Activity in Different Maturity Stages of Peanut

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ABSTRACT

The water activity (a_w) and kernel moisture content (KMC) of individual Florunner cv. peanut kernels representing five different maturity stages were measured during a period of late-season drought stress leading up to normal harvest time. Curves were generated describing the relationship between a_w and KMC for yellow 1, yellow 2, orange, brown, and black maturity stages as determined by the peanut hull scrape method. As peanuts matured, the KMC for a given a_w decreased. KMC in the most immature yellow 1 stage was extremely variable at higher a_w levels, indicative of the rapidly changing composition of kernels at that stage. The variation in KMC at high a_w decreased with increasing maturity. Equations to predict KMC for given a_w showed that KMC varied greatly among maturity stages, particularly at higher a_w. For example, at an a_w of 0.99 the predicted KMCs for yellow 1 (least mature) and black (most mature) stages were 62.7 and 30.7%, respectively. The degree of variation among stages decreased as a_w decreased in response to drought stress. Because preharvest aflatoxin contamination of peanuts is highly dependent on both the maturity stage of peanuts during periods of late-season drought stress and the resulting a_w of kernels, these KMC-a_w relationships can be utilized in efforts to breed peanuts for reduced susceptibility to aflatoxin contamination by focusing on genotypes that can maintain higher water activities during such late-season drought periods.

Key Words: Peanut, kernel moisture content, water activity, aflatoxin, *Aspergillus flavus*.

Peanut (*Arachis hypogaea*) is an indeterminate plant on which new fruit continues to be set throughout the growing season. Therefore, the determination as to when to dig plants is critical to ensure maximum yield because many of the heaviest pods can be lost during digging if allowed to become ''over-mature''. Even when harvest occurs at the optimum time, plants contain pods of varying physiological maturity, including some that are very immature. In certain years the percentage of immature pods can be relatively high, and this presents a variety of problems to different segments of the peanut industry. To the grower, a high percentage of immature pods means reduced yield and grade. To the buying point manager, it means farmers' stock loads are more difficult to dry without decreasing overall quality because of the higher moisture content associated with immature pods. Also, it is difficult to determine when a load has reached a kernel moisture content (KMC) that is safe for storage because individual KMCs can vary widely around the mean. To the warehouseman and/or sheller there is greater potential for aflatoxin contamination by *Aspergillus flavus* and *A. parasiticus* because higher preharvest aflatoxin concentrations are associated with immature kernels (Dorner *et al.*, 1989) and their higher KMC increases the risk of further contamination during storage. Finally, the manufacturer experiences problems associated with the different roasting characteristics of immature as compared to mature kernels as well as less desirable flavor.

In addition to the association of immature pods with higher levels of preharvest aflatoxin (Dorner *et*

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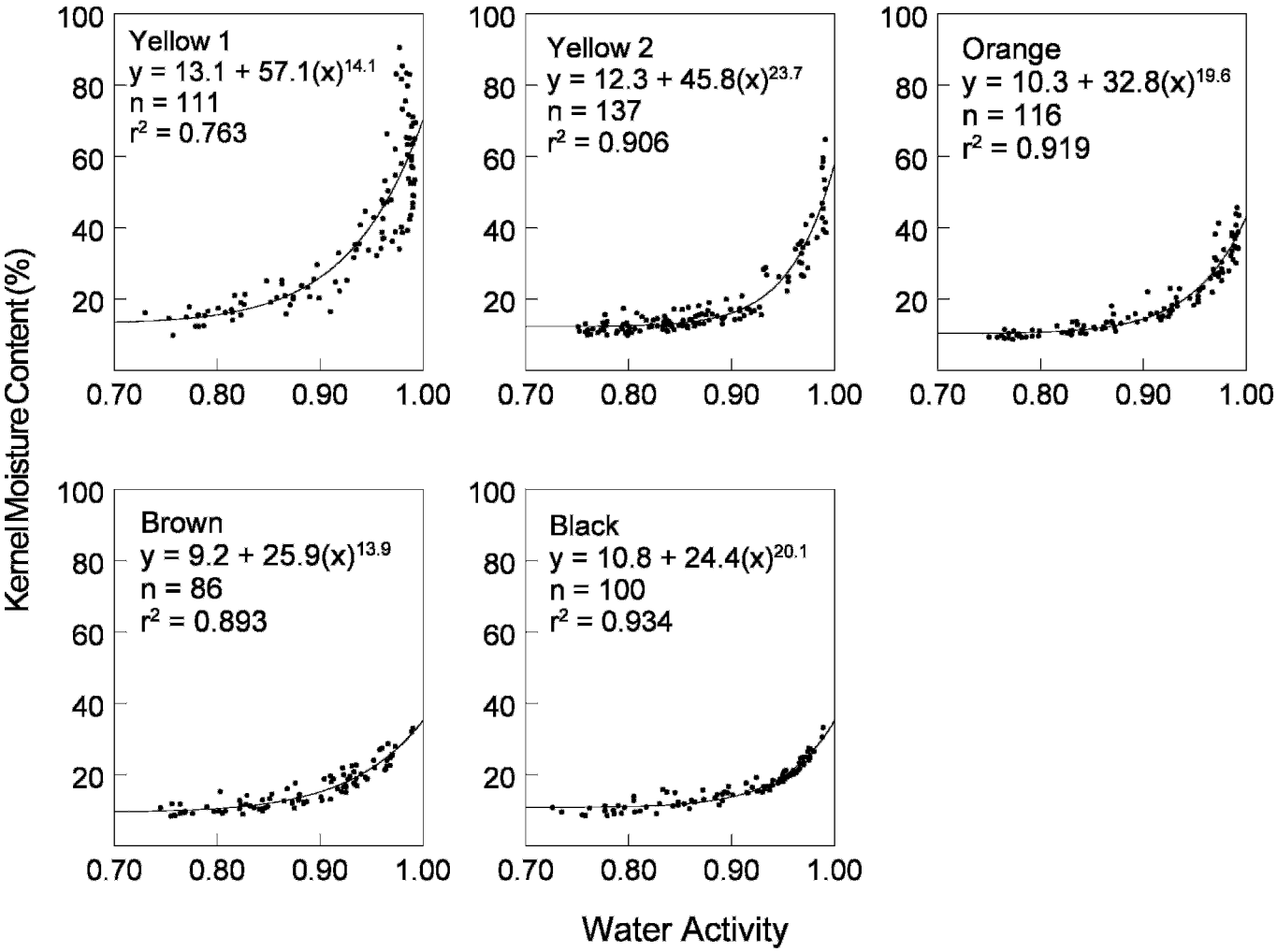

Fig. 1. Kernel moisture content-water activity curves for peanut kernels in five maturity stages.

al., 1989), it also has been shown that kernel water activity (a_w), or equilibrium relative humidity, is a major factor in aflatoxin contamination (Diener and Davis, 1968; Dorner *et al.*, 1989). The a_w of a food is defined as the ratio of the vapor pressure of the food to the vapor pressure of pure water at the same temperature and pressure (Scott, 1957), and it is equal to the equilibrium relative humidity divided by 100. The ability of *A. flavus* to grow in a substrate and produce aflatoxin is governed more accurately by a_w, not total KMC (Northolt and Bullerman, 1982). This is because a_w is a measure only of water that is actually available for fungal growth, while KMC includes water that is bound and unavailable. However, most determinations of the water content of peanuts are made by measuring total KMC only. Data generally are not available to convert total KMC to a_w because those relationships vary considerably among substrates. This presents difficulties in understanding the process of aflatoxin contamination in peanuts, particularly preharvest contamination resulting from extended late-season drought. The relationship between kernel a_w and total KMC is understood in general terms, and some KMC-a_w curves for peanuts have been published (Pixton, 1967; Pixton and Warburton, 1971); however, those curves were likely based on mature peanuts (no maturity designations were given) and they were confined to peanuts well below a KMC of 20% ($a_w < 0.90$). Dorner *et al.* (1989) pointed out that when the a_w of peanuts was high, there were large differences in total KMC among different maturity stages. However, there was no indication of how those differences changed as peanuts dehydrated under drought conditions. The purpose of this paper is to present relationships between KMC and a_w for freshly harvested peanuts in various maturity stages covering a wide KMC range.

Materials and Methods

Cultivar Florunner peanuts were grown in plots at the National Peanut Research Laboratory

Table 1. Dry weight statistics for kernels within each of five maturity stages.

Maturity Stage	n	Minimum (g)	Maximum (g)	Mean (g)	CV[a] (%)
Yellow 1	111	0.0049	0.5056	0.144	58.5
Yellow 2	137	0.1290	0.5776	0.332	30.7
Orange	116	0.0758	0.7576	0.447	28.0
Brown	86	0.2924	0.8258	0.522	18.6
Black	100	0.3839	0.9054	0.608	15.5

[a]Coefficient of variation.

Table 2. Predicted kernel moisture contents (%) for various water activities (a_w) in different maturity stages of peanut.

a_w	Yellow 1	Yellow 2	Orange	Brown	Black
0.99	62.7	48.4	37.2	31.7	30.7
0.97	50.3	34.6	28.3	26.1	24.0
0.95	40.8	25.9	22.3	21.8	19.5
0.93	33.6	20.5	18.2	18.6	16.5
0.91	28.2	17.2	15.4	16.1	14.5
0.89	24.2	15.2	13.6	14.3	13.1
0.86	19.9	13.6	12.0	12.4	12.0
0.82	16.6	12.7	11.0	10.8	11.2

equipped with a mechanized roof system to withhold rainfall during the last 40 days of the growing season to induce drought stress (Blankenship *et al.*, 1983). Prior to that time peanuts received full irrigation either from rainfall or an irrigation system mounted under each roof. Irrigation was optimized using the Irrigator Pro expert system (Davidson, *et al.*, 1998; Lamb *et al.*, 2004). During the last 4 weeks of the growing season, pod samples were collected periodically by digging several plants exhibiting varying degrees of stress based on visual assessment. Pods were hand-picked and placed in a wet impact blaster (Williams and Monroe, 1986) to remove the exocarp and expose the color in the mesocarp. Color and structural differences in the mesocarp were used to separate pods into five maturity stages (Henning, 1983; Williams and Drexler, 1981). This is commonly referred to as the hull scrape method and is the most commonly used method to determine the optimum time for digging peanuts. In order of increasing maturity, stages were yellow 1, yellow 2, orange, brown, and black, which correspond to stages 3–7, respectively, as described by Williams and Drexler (1981). The designations used here (yellow 1 to black) are those that appear on peanut profile boards that are widely used in the southeastern US and are available at most county extension offices in peanut-growing areas.

Pods were hand-shelled and individual kernels were placed in small air-tight containers and allowed to equilibrate to 25 C. Kernels were then weighed to the nearest 0.1 mg, and a_w was determined with an AquaLab model CX-2 water activity meter (Decagon Devices, Inc., Pullman, WA). KMC (wet weight) was then determined according to ASAE standard 410.1 (ASAE, 1993) by drying individual kernels for 6 h at 130 C. After drying, kernels were placed in a desiccator for temperature equilibration and then re-weighed. KMC was calculated as: (initial weight – final weight)/initial weight × 100.

Results and Discussion

The KMC and a_w of 550 kernels were measured, ranging from n = 86 for the brown maturity stage to n = 137 for the yellow 2 stage. The power function was used to describe the relationships between KMC and a_w for the five maturity stages, and curves and equations for those relationships are shown in Figure 1. The general relationship between KMC and a_w was similar among maturity stages, demonstrating a strong correlation between KMC and a_w. The strength of the correlation generally increased with increasing maturity.

When the a_w was relatively high, there were large differences in KMC among maturity stages with the more immature stages having much higher total KMC than mature stages. In addition, the immature stages had much more variation in KMC at high a_w levels. When the a_w was > 0.97, KMC in the yellow 1 stage ranged from 34.0 to 90.6%, but the degree of variation decreased as maturity increased. The larger variation in KMC associated with the more immature stages corresponds to rapid compositional changes that are occurring, such as with starch, sugar, and lipid contents (Pattee *et al.*, 1974). Statistics based on the dry weight of kernels are shown in Table 1 and illustrate decreasing variation in dry weight as pods mature. The pattern of decreasing variation in KMC at high a_w with increasing maturity (Figure 1) coupled with a similar decrease in variation associated with dry weight (Table 1) indicates that as pods mature within a maturity stage, rapid changes in total KMC occur in the immature stages with much smaller changes occurring in the more mature stages (brown and black).

Equations in Figure 1 were used to predict % KMC for a variety of a_w values (Table 2). There was extremely wide variation in % KMC among maturity stages at high a_w, ranging from 62.7% for the yellow 1 class to 30.7% for the black class at an a_w of 0.99. As the a_w decreased so did the variation in KMC among maturity stages, but even at the relatively low a_w of 0.82, the total moisture of

kernels from more immature pods was still higher than that from the more mature orange, brown, and black stages.

These KMC-a_w relationships have particular implications in studies of preharvest aflatoxin contamination of peanuts resulting from infection and growth by *A. flavus* and *A. parasiticus*. It has been reported that the minimum a_w for aflatoxin production in peanuts is about 0.85 (Diener and Davis, 1968). Furthermore, kernels from immature pods are more likely to be contaminated with aflatoxin than kernels from mature pods (Dorner *et al*., 1989). When kernels are at high a_w (> 0.95), they are unlikely to accumulate aflatoxin, presumably because of the ability of kernels to produce antifungal phytoalexins (Sobolev *et al*., 1995; Sobolev *et al*., 2007). As the a_w decreases during a period of extended drought, kernels eventually lose the capacity to produce phytoalexins and become contaminated (Dorner *et al*., 1989). The loss of phytoalexin-producing capacity occurs between an a_w of 0.98 and 0.95, making kernels particularly susceptible to aflatoxin contamination when the a_w is close to 0.95. As kernel a_w continues to decrease, the growth rate of the aflatoxigenic fungi and amounts of aflatoxins produced become limited. Therefore, the critical a_w for preharvest aflatoxin production in peanuts appears to be in the range of about 0.95–0.90. Although aflatoxin can be produced at a_w lower than 0.90, most of the preharvest aflatoxin that is produced in individual kernels probably accumulates as the kernel dehydrates through the optimum a_w range for *A. flavus* growth and aflatoxin production after phytoalexin production shuts down.

Although one cultivar was used in this study, it is expected that other cultivars and genotypes would react similarly as long as the composition (primarily oil content) is similar. In a comparison of equilibrium relative humidity (equivalent to a_w) and moisture relationships for various products, Pixton (1967) showed that differences were slight for different non-oily cereals, but for high-oil products differences were much greater. The major differences seen in this study among maturity groups is likely a function of their different oil contents. As oil content increased and became more stable with increasing maturity, differences in the KMC-a_w relationships became less.

The results presented here can be useful in aflatoxin modeling and breeding programs that are focused on development of peanut cultivars with greater resistance to aflatoxin contamination. One possible approach in development of such cultivars is to identify genotypes and germplasm that can maintain high kernel a_w for longer periods of time during a period of late-season drought (Dorner *et al*., 1991). Monitoring a_w during late-season drought, particularly in the more susceptible immature kernels, could help identify genotypes with the potential for reduced aflatoxin accumulation without the costly aflatoxin analyses that often yield extremely variable results. If measuring KMC is more convenient or cost-effective than measuring a_w, the equations in Figure 1 can be used to calculate a_w for a better assessment of susceptibility.

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