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Modified Atmosphere Packaging Bags of Peanuts with Effect of Inhibition of Aflatoxin Growth

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ABSTRACT: In this article, packaging bags composited with selective barrier film and moisture absorbent nonwoven fabrics were prepared to design a kind of functional bags, which can inhibit the growth of aflatoxin of peanuts. The influences of the superabsorbent fiber (SAF) and jute fiber on the internal relative humidity (RH) were investigated. It is found that jute nonwoven/selective barrier film composite bag can prevent the growth of aflatoxin B_1 of peanuts under the environment studied in this article because peanuts with higher moisture content can reduce O_2 content inside the bag by the aerobic respiration, achieving the modified atmosphere packaging (MAP) effect. In addition, a low RH micro-environment can be achieved by using SAF as moisture absorbent. It is promising to design a packaging bag with the effect of inhibition of the growth of aflatoxin of peanuts, by selecting proper moisture absorbent and selective barrier film of the composite bag. © 2013 Wiley Periodicals, Inc. J. Appl. Polym. Sci. **2014**, *131*, 40190.

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INTRODUCTION

Safe storing of grains has become an important issue around the world. Postharvest losses of grains can be up to 25%. As the World Food Programme spent $2.7 billion USD in 2007, to feed 86 million people, any postharvest improvements are likely to have significant economic impacts. Storage is a usual method to maintain products for a longer period. In 1917, English Science and Food Committee of Enquiry firstly found that the shelf life of apples can be extended by changing gas composition within the bag.[1] Since then, research on food storage has been flourishing, especially with the depletion of resources in recent years. Previous studies have demonstrated that packaging methods and storage can control the temperature, relative humidity (RH), and oxygen content inside the package, which all have big influences on the quality of products.[2–4]

Polymer film bags are widely used as packaging materials due to their excellent gas barrier properties, especially the composite film, such as polypropylene (PP)/ethylene-vinyl alcohol copolymer/polyethylene (PE), which are also called barrier films. Barrier films have good water moisture, oxygen, and carbon dioxide barrier properties.[5–7] In addition, moisture absorbent is often used in package of foodstuffs and medicaments to prolong preserving time by absorbing moisture inside the packaging.

In the packaging industry, effective methods have already been adopted to extend the storage stability of the product, such as modified atmosphere packaging (MAP), in which extra nitrogen or carbon dioxide is added so that the ratio of oxygen, nitrogen, carbon dioxide, and/or carbon monoxide is altered to best suit the food product by slowing down the growth of the aerobic organism and the speed of oxidation reactions.[8–10] Ellis et al.[11] studied the combined effects of water activity (a_w), storage temperature, headspace oxygen, and carbon dioxide concentrations on the growth of, and aflatoxin production by *Aspergillus flavus* on peanuts using a process optimization technique. They emphasized the combined effect of several 'barriers' to inhibit and reduce aflatoxin in MAP products. Paramawati et al.[12] studied the role of packaging in minimizing aflatoxin contamination in peanut. They found that hermetic packaging provides a good solution to achieve low aflatoxin level after storage compared to polyethylene and vacuum packaging (PE/PET). But in certain cases, the product is packaged in wet. The water moisture inside the package will influence the quality of the product. Hence the packaging container should have good moisture absorption property, which is not solved by MAP.

Peanuts are a dietary mainstay in Asia and Africa. They are susceptible to molds and fungal invasions. Of particular concern is aflatoxin, a poison produced by a fungus called *Aspergillus flavus*. Aflatoxins are naturally occurring mycotoxins. They are a family of closely related compounds, which include aflatoxin B_1, B_2, G_1, and G_2, however aflatoxin B_1 is usually in the highest concentration and the most toxic.[13] Moisture is a primary

Figure 1. Photo of jute nonwoven/selective barrier film composite bag. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

factor in control of the growth of *Aspergillus flavus*. Warm and humid condition is ideal for it to thrive. RH below 75% is normally accepted as 'safe' for storage of food commodities. On the other hand, *Aspergillus flavus* is a kind of aerobic bacteria. Its growth can be inhibited under anaerobic conditions. Peanuts stored in the several treatments have been studied to inhibit the growth of aflatoxin of peanuts.[14–16] But little has been reported on packaging material design for peanuts.

In this article, packaging bags composited with selective barrier film and moisture absorbents were designed to find out how to form a micro-environment with low O_2 content and RH, in which the growth of aflatoxin of peanuts can be inhibited. Super-absorbent fiber (SAF) and jute fibers are used as moisture absorbents to absorb moisture inside the packaging. As traditional packaging materials, jute fiber, a kind of natural fiber, has been widely used as packaging bags for grains with excellent hygroscopicity and moisture retention properties.[17,18] SAF is a kind of fibrous superabsorbent mainly composited with acrylic acid polymers, which is widely used as agro textiles, medical textiles, and packaging textiles, etc., exhibiting extremely high rates of water uptake.[19] The micro-environment inside the bags stored with peanuts was monitored. The influences of the selective barrier film and the moisture absorbents of the composite packaging bags on the micro-environment were analyzed as well.

MATERIALS AND METHODS

Materials

Peanuts with moisture content of 6.9% were bought from the supermarket. Impurities and broken peanuts were sorted out and then the peanuts were moistened to the targeted moisture content for storage experiment.

The selective barrier film used in this article has O_2, CO_2, and water vapor transmission rate of 0.3 cm^3 $(m^2 \cdot 24\ h \cdot atm)^{-1}$, 0.8 cm^3 $(m^2 \cdot 24\ h \cdot atm)^{-1}$, and 20 g $(m^2 \cdot 24\ h)^{-1}$, respectively. The thickness of the film is 0.675 mm.

Three kinds of packaging bags, e.g., jute nonwoven fabric bag, jute nonwoven/selective barrier film composite bag, and SAF nonwoven bag covered with selective barrier film were made as follows.

Jute fibers blended with low-melt core/sheath PE/PP fibers with the ratio of 60/40 were carded and needle-punched into a loft fiber web. The web was thermally bonded into jute nonwoven fabric with the basis weight of 150 g/m^2. At last, the jute nonwoven fabrics were made into bags with the size of 32 × 33 cm for the following aflatoxin contamination measurement.

The jute nonwoven fabric was further thermally laminated with the selective barrier film and then made into bags with the size of 32 × 33 cm, as shown in Figure 1.

SAF fibers blended with low-melt core/sheath PE/PP fibers and viscose fiber with the ratio of 50/30/20 were carded and needle-punched into a kind of nonwoven fabric with basis weight of 270 g/m^2. SAF nonwoven fabric was made into bags with the same size of 32 × 33 cm. The bags were covered with the selective barrier film by thermal pressing for storage experiment, as shown in Figure 2.

Methods

Measurement of the Content of Aflatoxin B_1 of Peanuts. The content of aflatoxin B_1 of peanuts was measured by Shanghai Municipal Center for Disease Control & Prevention according to GB/T 18979-2003-determination aflatoxin content in food-cleanup by immunoaffinity chromatography and determination by high-performance liquid chromatography and fluorometer.

Peanuts were ground into fine powder less than 2 mm and 25.0 g peanut powder was put into a conical flask. Five gram of NaCl and 125.0 mL methanol aqueous solution with concentration of 70% were added into the flask. The solution was stirred under high speed for 2 min. Then the extracted solution was filtered for further use.

A immunoaffinity column was connected with a glass syringe. Fifteen milliliter extracted solution was injected into the glass syringe. The column was purified and washed finally by using chromatographic grade methanol. The purified solution was collected in a glass tube for further use.

A standard solution of aflatoxin B_1 was injected into a high-performance liquid chromatography and a standard chromatogram of aflatoxin B_1 was obtained. Then the purified solution was injected into the chromatography for quantification.

Figure 2. Photo of SAF nonwoven bag covered with selective barrier film. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

Table I. The Water Activity of Saturated Salt Solutions Under 25°C

Salt	Water activity
KOH	8.0
K_2CO_3	42.8
NaBr	57.6
NaCl	75.3
KNO_3	92.5

Measurement of O_2 and CO_2 Content Inside the Jute Nonwoven/Selective Barrier Film Composite Bags During the Storage of Peanuts. A sample of 2500 g peanuts with moisture content of 8, 10, and 13% were sealed in the jute nonwoven/selective barrier film composite bags, respectively. Three bags were put in a LHH-250SDP model Environmental Chamber (Shanghai Yiheng Instruments, China) for 15 days, which was controlled under 30°C and RH95%. During the storage, the content of O_2 and CO_2 inside the bags were measured by using a Checkpoint- Handheld Gas Headspace Analyzer (PBI-Dan sensor, Denmark) every 2 days.

Measurement of the RH Inside Packaging Bags. A sample of 2500 g peanuts with moisture content of 13% were sealed with the RH recorder into the packaging bags. The bags were put in the environmental chamber for 15 days, which was controlled under 30°C and RH95%. The RH inside the bags was recorded every 10 min by the humidity recorder.

Isothermal Moisture Absorption Characterization of Jute Fiber, SAF, and Peanuts. The isothermal moisture absorption characteristics of jute fiber, SAF, and peanuts were studied by using a Conway's diffusion method. Jute fiber, SAF, and peanuts were dried in an oven under 105°C until their weight changed less than 0.01% within 2 h. A small piece of aluminum foil was put into the Conway unit center and 1 g sample was put on the foil. Saturated salt solutions listed in Table I were placed around the center of the Conway unit.[20] Then the Conway units were covered by a glass plate and put in the environmental chamber under 25°C and RH 65%. The foil together with the sample was weighed every 2 h until their weight changed less than 0.01%. The equilibrium moisture content of samples are calculated according to eq. (1)

$$R_1=\frac{|G-G_0|}{G_0}\times 100\% \quad (1)$$

where R_1 is the equilibrium moisture content of the sample, %; G_0 is the initial weight of the sample, g; G is the balanced weight of the sample, g.

Measurement of Moisture Content of Peanuts. The moisture content of peanuts was measured according to GB5497-85. Fifty gram peanuts were randomly selected from the sample. Then they were ground and approximately 3 g (± 0.001 g) peanut powder was dried in the oven under 105°C for 3 h until the weight difference within 30 min was not higher than 0.005 g. The moisture content of peanuts (R_2) is calculated as follows:

$$R_2=\frac{|W_2-W_1|}{W_2}\times 100\% \quad (2)$$

where R_2 is the moisture content of peanuts, %; W_1 is the initial weight of peanuts, g; W_2 is the dried weight of peanuts, g.

Table II. Aflatoxin B_1 Content of Peanuts After Storage in Different Bags

Samples	1	2
Moisture content of peanuts (%)	13	13
Aflatoxin B_1 content (μg/kg)	2.6	0

RESULTS AND DISCUSSION

Aflatoxin B_1 Content of Peanuts After Storage in Different Bags

In this article, peanuts with moisture content of 13% were sealed in the jute nonwoven fabric bag and jute nonwoven/selective barrier film composite bag and stored in the environmental chamber under 30°C and RH95% for 80 days. Then they were taken out and their content of aflatoxin B_1 was measured as shown in Table II. The samples are named as Sample 1 and Sample 2, which correspond to peanuts stored in the jute nonwoven fabric bag and jute nonwoven/selective barrier film composite bag, respectively.

It can be found from Table II that there was no detectable aflatoxin B_1 in the peanuts stored in the jute nonwoven/selective barrier film composite bag, while the content of aflatoxin B_1 of peanuts stored in the jute nonwoven fabric bag was 2.6 μg/kg, suggesting that the jute nonwoven/selective barrier film composite bag exhibited positive effects on preventing the growth of aflatoxin B_1 of peanuts under the environment studied in this article. To uncover the reason, the micro-environment inside the bags was investigated as follows.

Changes of O_2 and CO_2 Content Inside Jute Nonwoven/Selective Barrier Film Composite Bags During the Storage of Peanuts

Peanuts with moisture content of 8, 10, and 13% were sealed in the jute nonwoven/selective barrier film composite bags and stored in the environmental chamber for 15 days. Changes of O_2 and CO_2 content within the bags were monitored by using a gas analyzer, as shown in Figure 3.

As we know, the initial content of O_2 and CO_2 within the bags is 20.95 and 0.03% when peanuts were filled, the same as the

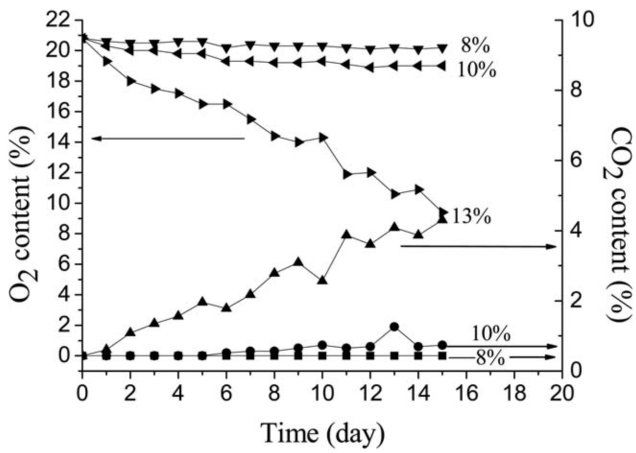

Figure 3. O_2 and CO_2 content within bags during the storage of peanuts with moisture content of 8, 10, and 13%.

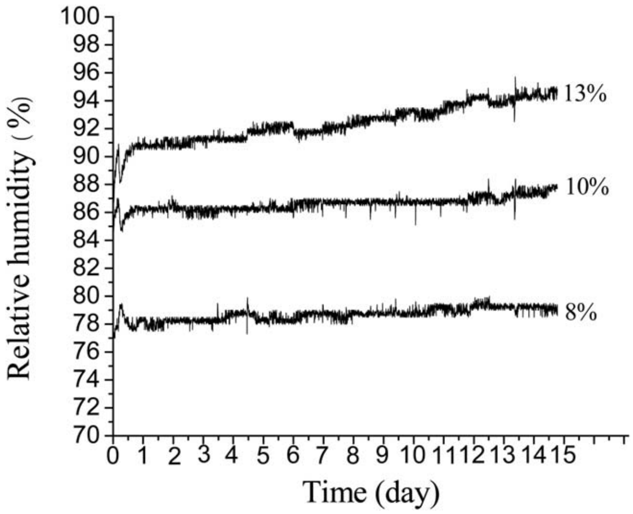

Figure 4. Changes of RH inside bags filled with peanuts with moisture content of 8, 10, and 13%.

normal atmospheric conditions. It is interesting to find from Figure 3 that the content of O_2 inside the bag stored with peanuts with moisture content of 13% decreased sharply and the content of CO_2 increased correspondingly, while the content of O_2 and CO_2 did not change obviously for bags filled with peanuts with moisture content of 8 and 10%. At the end of the storage for 15 days, the content of O_2 and CO_2 inside the bag stored with peanuts with moisture content of 13% were 9.4 and 8.9%, respectively. Weinberg et al.[21] sealed maize with high moisture in glass jars for 75 days and found that CO_2 produced within the containers replaced O_2. They also found that the time for O_2 depletion decreased as the moisture content of maize increased, which is consistent with the findings in this article.

The selective barrier film used in this article has low O_2 and water vapor transmission rate. Hence a hermetic system was formed inside the jute nonwoven/selective barrier film composite bag. Peanuts will undergo aerobic respiration in the initial storing period because there is enough O_2 inside the bag.[22] With the process of aerobic respiration, O_2 within the bag is consumed by peanuts and CO_2 is released at the same time. On the other hand, it is said that the aerobic respiration intensity of grains is greater at increased moisture content.[23] It is believed that the aerobic respiration intensity of peanuts with moisture content of 8 and 10% is weak. Hence O_2 and CO_2 content within the bags did not change obviously. However, peanuts with moisture content of 13% underwent strong aerobic respiration in the initial storing stage. Hence the content of O_2 was decreased while the content of CO_2 was increased. This means that the jute nonwoven/selective barrier film composite bag can partly achieve the MAP effect only by the aerobic respiration of peanuts with higher moisture content.

It is reported that the growth of, and aflatoxin production by *Aspergillus flavus* decreases with the decrease of oxygen concentration.[24] Hence peanuts stored in the jute nonwoven/selective barrier film composite bag did not contaminate with aflatoxin B_1 under the environment studied in this article.

Changes of RH Inside Jute Nonwoven/Selective Barrier Film Composite Bags During the Storage of Peanuts

Grains can be stored for longer period of time in a dry environment. Therefore it is necessary to know the RH inside the jute nonwoven/selective barrier film composite bag filled with peanuts. In this article, a humidity recorder was sealed inside each bag filled with peanuts with different moisture content and the RH inside the bags was recorded, as shows in Figure 4.

It can be found from Figure 4 that the higher the initial moisture content of peanuts, the higher the final RH inside the bag. It can also be seen from Figure 4 that a peak appeared on each curve in the early stage of storage experiment and then the RH started to increase and nearly balanced at a higher level. This means that the jute nonwoven/selective barrier film composite bag only absorbed moisture inside the bag in the early stage. After it reached balanced, the RH inside the bag started to increase.

To understand the total humidity changes inside the bags, the moisture content of peanuts and composite bags before and after the storage experiment were measured and the results were shown in Table III. The samples are named as Sample 3, Sample 4, and Sample 5, which correspond to the bags filled with peanuts with initial moisture content of 8, 10, and 13%, respectively.

From Table III we can see clearly that the moisture content of all peanuts increased after storage for 15 day. It is believed that moisture in the environmental chamber penetrated into the bag because of the inside and outside RH difference. It can also be found from Table III that the moisture content of peanuts with initial moisture content of 13% increased more obviously compared with the other two samples. To understand the mechanism, the equilibrium moisture content of peanuts under different final RH conditions balanced in every bag were listed in Table IV.[25]

It is found from Table IV that the moisture content of peanuts with initial moisture content of 9.5 and 11.5% was finally in equilibrium during the storage when they absorbed 37.5 g moisture, while peanuts with moisture content of 15.8% could

Table III. Changes of Moisture Content of Peanuts and Packaging Bags

Samples	3	4	5
Initial moisture content of peanuts (%)	8	10	13
Final moisture content of peanuts (%)	9.5	11.5	15.8
Moisture absorbed by peanuts (g)	37.5	37.5	70.0
Original weight of the bag (g)	62.1	62.1	62.1
Final weight of the bag (g)	63.8	64.8	69.6
Moisture absorbed by the bag (g)	1.7	2.7	7.5

Table IV. Equilibrium Moisture Content of Peanuts Under 30°C and Different RH

Sample	3	4	5
Initial moisture content (%)	8	10	13
Final moisture content (%)	9.5	11.5	15.8
Equilibrium moisture content (%)	9.3 (RH75%)	11.3 (RH85%)	20 (RH90%)

still absorb moisture at the end of the storage experiment. Hence the final moisture content of peanuts with initial moisture content of 13% increased more than that of the other two samples. On the other hand, it is found that the bags absorbed less moisture than peanuts. This means that peanuts have better moisture absorption property than the jute nonwoven fabric.

Although peanuts with moisture content of 13% did not contaminate aflatoxin B_1 when they stored in the jute nonwoven/selective barrier film composite bag under the conditions studied in this article. It is not safe to store them for longer period because their moisture content will increase much higher with the extension of the storage. Therefore, the moisture absorption capacity of the bag should be improved to keep the peanuts in a lower humidity environment. In this article, SAF was selected as the moisture absorbent and its effect was studied as follows.

Changes of RH Inside SAF Nonwoven Bag Sheathed With Selective Barrier Film

SAF was processed into the composite packaging bag according to the method as described above. Peanuts with moisture content of 13% were filled into the SAF nonwoven bag covered with selective barrier film and stored in the environmental chamber under 30°C and RH95%. The RH inside the bags was monitored and the results were shown in Figure 5. In comparison, the internal RH inside the jute nonwoven/selective barrier film composite bag was also shown in Figure 5.

It is interesting to find from Figure 5 that the RH inside the SAF nonwoven bag covered with selective barrier film decreased slowly and balanced at about RH80%, which is much lower than that of the jute nonwoven/selective barrier film composite bag. This means that SAF is more effective than jute fiber to decrease the RH inside the packaging bag. In other words, the RH inside the bag can be modified by choosing the proper absorbent component of the composite bag.

Furthermore, the changes of moisture content of peanuts and the bag were measured and shown in Table V, which is named as Sample 6.

It can be found from Table V that the moisture content of peanuts decreased from 13 to 10.5%. In other words, SAF absorbed moisture while peanuts released moisture during the storage experiment. To uncover the reason, their isothermal moisture absorption properties were further measured by using the Conway' diffusion method.

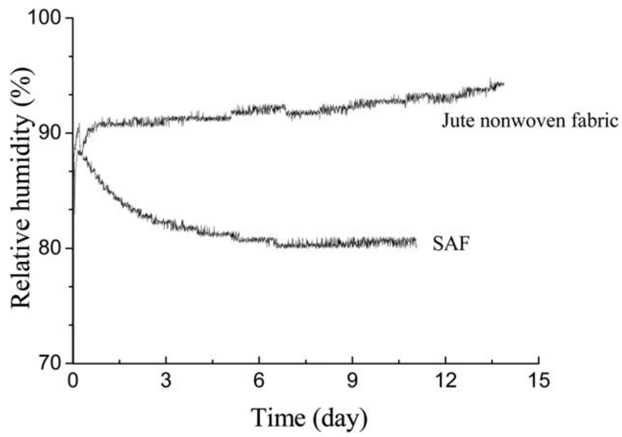

Figure 5. RH changes inside two bags filled with peanuts.

Isothermal Moisture Absorption Properties of Jute Fiber, SAF, and Peanuts

To uncover the reason why SAF has better effect of decreasing the moisture content inside the packaging bag stored with peanuts, the isothermal moisture absorption properties of jute fiber, SAF, and peanuts were measured and the results were shown in Figure 6.

It can be found from Figure 6 that the equilibrium moisture content of jute fiber and peanuts increased slightly with the increase of the water activity in a similar trend, which means that jute fiber and peanuts have similar cohesion and absorption capacity to water molecular in the wide range of water activity. When the jute fiber is used as moisture absorbent of the packaging bag of peanuts, it is hard for peanuts to release moisture. However, it can be found from Figure 6 that the equilibrium moisture content of SAF increased sharply with the increase of the water activity. The moisture adsorption capacity of SAF is significantly stronger than that of jute fiber and peanuts, especially under the higher water activity condition, suggesting SAF has higher cohesion to water molecular than peanuts and jute fibers. Therefore, water moisture was released by peanuts and then absorbed by SAF when peanuts with moisture content of 13% were stored in the SAF nonwoven bag covered with selective barrier film. A lower RH in the packaging bag was achieved correspondingly.

Table V. Changes of Moisture Content of Peanuts and Bags

Samples	5	6
Initial moisture content of peanuts (%)	13	13
Final moisture content of peanuts (%)	10.5	15.8
Moisture absorbed/released by peanuts (g)	−62.5	+70
Original weight of the bag (g)	292.8	62.1
Final weight of the bag (g)	362.4	69.6
Moisture absorbed by the bag (g)	69.6	7.5

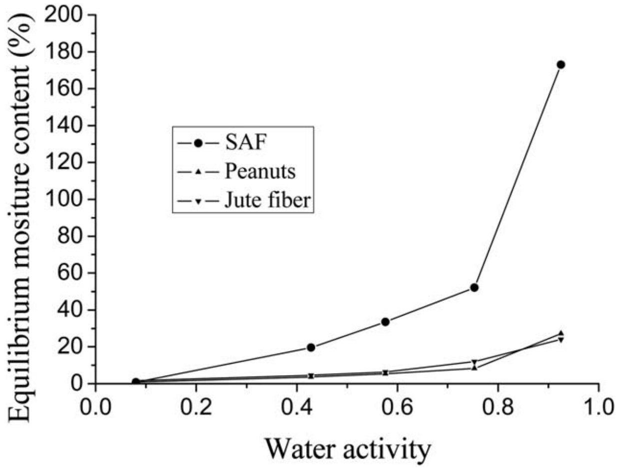

Figure 6. Isothermal moisture absorption curves of jute, SAF, and peanuts.

CONCLUSION

In this article, functional packaging bags composited with selective barrier film and moisture absorbent nonwoven fabrics were designed with the aim of inhibiting the growth of aflatoxin B_1 of peanuts during storage. The internal moisture humidity was monitored and the influences of jute fiber and SAF were compared. The following conclusions can be achieved.

Jute nonwoven/selective barrier film composite bag is effective to prevent the growth of aflatoxin B_1 of peanuts under the environment studied in this article.

Peanuts with high moisture content can decrease O_2 content inside the packaging bag composited with selective barrier film by aerobic respiration, achieving the modified atmosphere packaging effect.

SAF showed higher equilibrium moisture content than peanuts in the whole range of water activity, especially in the higher water activity. Hence a micro-environment with lower RH can be achieved by using SAF as the moisture absorbent of the composite packaging bag. It is believed that SAF nonwoven bag covered with selective barrier film has better effect to prevent the growth of aflatoxin B_1 of peanuts for longer period.

It is promising to design a packaging bag, which can create a micro-environment with low RH and high CO_2 content by selecting proper moisture absorbent and selective barrier film of the composite bag, with the function of inhibiting the growth of aflatoxin B_1 of peanuts.

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