J. Milk Food Technol., Vol. 36, No. 9 (1973)

# ADAPTABILITY OF POTATO DRYING TO YAM PROCESSING[1]

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(Received for publication March 2, 1973)

Abstract

One of the problems related to the food supply in Nigeria and other West African countries at present is that of efficient preservation and processing of raw products. In this brief review of potato processing techniques, properties of West African yams are compared with those of potato with a view to explore possibilities of adapting potato processing techniques to yams. Yams referred to in this article are of the family *Dioscoreaceae*, and they are different from the yams known in the U.S.A. The American yams are of the family *Convovulaceae* and are a variety of sweet potatoes. Possible new foods from West African yams, similar to convenience foods made from potato are also proposed. Of the varieties of yam grown in Nigeria, *Dioscorea alata* (water yam) is compositionally closest to potato. Properties of other varieties also are comparable to those of potato. Because there are similarities between the two tuberous crops, various methods for dehydrating potato could be adapted to drying of the West African yam.

## Introduction and Background Information

The objective of this review of potato dehydration is to provide a basis for developing techniques to dry varieties of West African yams which have characteristics similar to the potato.

Yams are tuberous crops indigenous to the humid, tropical, southern parts of West Africa where they are used as an important source of carbohydrate. They are the most important root crop produced in Nigeria. West African yams are different from the yams known in the United States of America. American "yams" are a variety of sweet potatoes. American varieties of sweet potatoes are classified into two main groups: *(a)* varieties grown primarily for feed and industrial uses and *(b)* varieties grown primarily for food. The food types are further divided into two subgroups: varieties with soft or moist flesh when cooked, and varieties with firm or dry flesh when cooked *(5, 7)*. In the United States, growers, shippers, and buyers of the moist-fleshed types frequently use the term "yam" *(5)*. In fact the term "yam" as it is used in the United States is a misnomer for a variety of sweet potato. The group of plants which has been classified by plant scientists as yams are quite distinct from and not even closely related to the sweet potato. In general, the sweet potato is a member of the family *Convolvulaceae* – the morning glory family *(5)*. It is a dicotyledon with net-veined leaves. On the other hand, the yam is a member of the family *Dioscoreaceae*. It is a monocotyledon and in general has arrow shaped leaves, and flower parts occur in groups of three or multiples of three. At present yams are not grown commercially in the United States except for one kind, *Dioscorea batatis*, the chinese yam which is being cultivated on a small commercial scale in California *(1, 5)*.

There are many varieties of yam grown in Nigeria, and early work of the Agricultural Department of Nigeria recognized six groups or species of the genus *Dioscorea* from which the cultivated yam of Nigeria is derived *(11)*. The cultivated species are: *Dioscorea rotundata* (white yam), *D. cavanensis* (yellow yam), *D. alata* (water yam), and *D. dumentorum* (trifoliate yam, "esuru").

*D. rotundata* (white yam) is the most popular and the many varieties within this group are widely grown in different parts of Nigeria. The subvarieties are classified as to the nature of carbohydrate content–whether mealy or hard or suitable for use as pounded yam "iyan" or to be eaten as such when boiled in water. The other varieties are also important and are used widely as food, although most of the food products, "iyan" (pounded yam), "amala" (yam flour reconstituted in boiling water), and sometimes cakes and fried yams similar to "French fries", are all derived from *D. rotundata.*

One of the species of *Dioscorea* that requires special attention, although used less as food, is *D. alata* (water yam). It differs from other varieties in character and use of the tuber. This variety normally affords greater yields and does better than other varieties in soils of very low fertility. It has a thick dry coat next to the skin enclosing the flesh which has more water than the flesh of other varieties of yams. This is readily noticeable when the tuber is cut. The cut tuber undergoes browning more readily when exposed to air than the other varieties. The tuber is not suitable for pounding, but may be grated before boiling and made into porridge with vegetable oil,

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TABLE 1. PROXIMATE ANALYSIS OF YAM TUBERS,[1] POTATOES, AND SWEET POTATOES

| Species | Moisture content (%) | CHO (%) | Fat (%) | Crude Protein (%) | Fiber & ash (%) |
|---|---|---|---|---|---|
| *D. alata* | 65-73 | 22-29 | 0.03-0.21 | 1.12-2.78 | 1.3-3.4 |
| *D. cavanensis* | 83 | 15 | 0.05 | 1.02 | 0.93 |
| *D. rotundata* | 58-73 | 23 | 0.12 | 1.09-1.99 | 1.03-3.1 |
| *D. dumentorum* | 79 | 17 | 0.28 | 2.78 | 1.02 |
| Potatoes | 68-82 | 14-27 | 0.02-0.18 | 1.14-2.98 | 1.06 |
| Sweet potatoes | 58-81 | 17-43 | 0.18-1.66 | 0.45-4.37 | 1.20 |

[1]Potato and sweet potato are included in this table for comparison (19). Adapted from D. G. Coursey (3).

green vegetables, shrimp, flavorings such as "egunsi" (powdered melon seeds after the shells of the seeds have been removed), and other condiments. It has been shown that *D. alata* contains relatively more protein than the other varieties *(10)*, and its protein content (Table 1) is comparable to that of the potato *(3)*.

The greatest problems with yams, and which need immediate solutions, are the seasonal variability in supplies and the inadequacy of yam food products for providing essential nutrients. There are times of the year between the rainy months (June to late October) when there are large supplies of the different varieties of yam. However, because efficient preservation and processing are lacking, yams and yam products are very scarce and expensive during the dry months.

The respiration rate of yams is much higher than that of other plant products. Perhaps this causes the very rapid conversion of polysaccharides in yams to hexose sugars during traditional storage. The high respiration rate accounts for the early "death" of the yam tissue. No successful storage method has been developed for yam tubers. Hence, the only and surest way to effectively distribute yams and food products derived from yams throughout the year would be through use of a dehydration process to prepare various food products similar to dehydrated potato products.

Canning is usually a convenient method to preserve and distribute food products. American "yams" (sweet potatoes) are usually canned in sucrose or common table syrup. Usually, the potatoes are firmed by soaking in a 0.5% citric acid solution for 20-24 hr before canning. Use of a 40% syrup is then necessary to mask the acid flavor resulting from soaking in the acid solution. Canning of West African yams may not be economically feasible at the present time. Aside from the fact that such syruped canned yams similar to canned potatoes may not meet consumer acceptability, the cost of canning in Nigeria and other West African countries at the moment is exorbitant. It would, therefore, be of greater advantage to explore the possibilities of improving the existing techniques of yam processing.

The objectives of this review, therefore, are to *(a)* compare the apparent properties of yams with those of potato, *(b)* reiterate some of the latest techniques that have been used to dehydrate potato and discuss possibilities of their applicability to yam drying, and *(c)* discuss possible new food products, similar to convenience foods made from potatoes and the possibility of their being acceptable to consumers.

## COMPOSITION OF VARIETIES OF YAMS AS COMPARED WITH POTATOES

There have been attempts at providing a detailed chemical composition of yam tubers rather than regarding them only as masses of starch as many nutritionists have done. It has been shown that a small proportion of the total carbohydrate consists of mono- and disaccharides, probably intermediates in the metabolic breakdown of starch. Observations using a paper chromatographic technique have indicated that freshly harvested *D. rotundata* contains two principal sugars; sucrose is present in larger amounts than glucose *(3)*. A trace amount of fructose was also detected. Accumulation of sucrose instead of glucose is evident from the very sweet taste developed by certain subvarieties of *D. rotundata* after some storage.

Yam tubers also contain small but significant amounts of protein, usually between 1-2% and occasionally as high as 3%. The protein contents of some yam species are lower than that of potatoes, but other varieties such as *D. alata* and *D. dumentorum* have comparable levels of protein (Table 1). The amino acid composition of protein in the yam tuber is not known with certainty. A partial analysis of the Japanese varieties, *D. opposita* and *D. japonica*, indicated low contents of sulfur bearing amino acids and lysine but large amounts of tryptophan and arginine *(16)*.

From data in Table 1, it appears that *D. alata* is closest to the potato in composition. The carbohy-

TABLE 2. VITAMIN C CONTENT OF VARIETIES OF YAM[1]

| Variety | Vitamin C (mg/100g) |
|---|---|
| *D. rotundata* | 6.5 - 11.6 |
| *D. cavanensis* | 4.5 - 8.2 |
| *D. alata* | 5.8 - 8.2 |

[1]Adapted from Coursey *(3)*. The average vitamin C content for the edible portion of potatoes is 17 mg/100 g *(18)*.

TABLE 3. VITAMIN C RETENTION DURING YAM PROCESSING[1]

| Process | Percent of Vitamin C retained |
|---|---|
| Boiling (without peeling) | 95 |
| Frying (in Palm oil) | 93 |
| Roasting or baking | 85 |
| Boiling after peeling | 65 |

[1]Adapted from D. G. Coursey *(3)*

drate, protein, and moisture contents are similar.

Some yams contain some toxic and pharmacologically active substances. It has been noted *(3b)* that the tubers of many wild species of yam are so toxic as to be dangerous to human life, and some have been used deliberately as sources of poison for hunting and fishing. The majority of the toxic materials belong to three classes of compounds: alkaloids, tannins, and saponins.

Alkaloids have been detected in at least seven of the species of yam examined but the largest amounts are found in *D. dumentorum* and *D. hispida* with smaller quantities in *D. alata*. The alkaloid, dioscorine, occurs in the tubers of *D. hispida* and its derivative, dihydrodioscorine, occurs in some varieties of *D. dumentorum* which is closely related to *D. hispida*. Doscorine is a potent neurotoxin, causing a general paralysis of the central nervous system. Dihydrodioscorine is also toxic, acting as a convulsant poison, but the toxicity appears to be milder than that exhibited by the parent compound. It is the dihydrodioscorine that has been found in the West African species of *D. dumentorum (1a)*. Fortunately, the extremely poisonous dioscorine is soluble in water, and hence in the traditional cooking of yams tubers are detoxified by washing employed. The toxin is also soluble in chloroform and methanol.

Little is known of the exact nature of the tannins in yams although occurrence of these compounds have been reported in *D. cirrhosa* and the dark red-fleshed form of *D. alata*.

The third main class of compounds of pharmacological importance occurring in yams are the saponins which are glycosides consisting of a sugar residue (one or more units of glucose or galactose) linked through oxygen to a triterpenoid. Development of foam when pieces of yam tuber are shaken with water is an indication of the presence of these soapy substances. Saponins have very powerful hemolytic actions, and for this reason, they are highly toxic if injected directly into the blood stream. However, they are generally inactive when ingested through the mouth, because they are perhaps hydrolyzed in the digestive system or possibly the ingested substances are not absorbed from the intestine. Saponins, however, have a bitter taste, and yams containing substantial quantities are generally not eaten.

There has been no explanation for *(a)* the various colors associated with varieties of raw yam tubers, *(b)* certain types of discoloration that occurs when the raw tuber is cut, or *(c)* darkening of the reconstituted flour derived from *D. rotundata* "amala." It is not unlikely that yam tubers contain definite (but perhaps small) amounts of phenolic and related substances such as flavones, anthocyanins, and monohydric and polyhydric phenols similar to those found in the potato tuber *(15)*. The yellow coloration of *D. cavanensis* which is not leached into the cooking water apparently results from the presence of fat-soluble pigments possibly carotenoid compounds.

Perhaps the most important of the minor constituents of yam tubers are vitamins, especially vitamin C. These occur in quantities large enough to contribute substantially to human nutrition in yam consuming areas. A more detailed study *(4)* made in Ghana of varieties of *Dioscorea* revealed the vitamin C contents shown in Table 2. In view of the close similarities between potato and yam tubers, it is most likely that techniques and precautions taken in processing potatoes into various forms with a long shelf life might be applicable to yam processing.

## POTATO DEHYDRATION TECHNIQUES

No attempt is made in this short discussion to review all techniques used in potato processing. Rather, a few of the recent developments in technology which might lend themselves to yam processing are reviewed. The feasibility of applying these processes to making new products from yams are briefly explored.

### *Potato flakes by drum drying*

Drum drying is the most commonly used method to dry potatoes. In this process, raw potatoes are sliced after peeling and the sliced potatoes are precooked and cooled. Potatoes are then mashed or riced, after which additives to improve product flavor, stability, and texture are added to the riced potato before it is dried. Sodium sulfite and sodium bisulfite are used to prevent oxidative changes during processing and to improve the shelf-life. Usually, an antioxidant "Tenox V,"[3] a mixture of butylated hydroxytoluene (BHT), butylated hydroxyanisole (BHA), propyl gallate, citric acid, propylene glycol, and vegetable oil, is used as a preservative against oxidative deterioration.

The mashed potato is dried by feeding it to the top surface of a single-drum drier. A two-way ribbon screw, rotating oppositely to the drum distributes the wet mash uniformly on the surface of the drier. Small-diameter unheated rolls progressively apply fresh mash to that already partially dried, thereby filling the interstices and building up a dense sheet. The sheet is dried by steam in the drum at 75-80 psig and a drum speed of 2 rpm. Under these conditions moisture in the mash is reduced from 80% to 4.5 to 5% in approximately 2 min. The dried sheet is peeled away from the drum surface by a "doctor" knife, but if a good dense sheet is made, it usually peels away from the drum just ahead of the knife and leaves the drum surface quite clean. A slitting roll and a transverse cutting roll convert the sheet into half-inch square flakes.

A process of flakelet manufacture developed by Pader *(12)* uses a high level of monoester of a polyhydric alcohol containing at least three hydroxy groups and a saturated higher fatty acid. The compound is thoroughly mixed with the cooked potatoes before drying. Inclusion of the monoester results in a dehydrated potato product which, on reconstitution has textural and other characteristics of freshly prepared mashed potato. In many instances, the quality of the reconstituted dehydrated product surpasses the quality of freshly prepared mashed potatoes of the same type. In addition, the quality of the reconstituted product is further improved by addition of edible protein such as calcium or potassium caseinate, whole milk solids, skim milk solids, or soybean protein isolates to the cooked potato before drying. The edible protein improves drum drying characteristics of the mashed potato containing the monoester *(12)*.

Development of a food product from yams similar to mashed potatoes is desirable since reconstituted mashed potatoes are quite similar in color and texture to the pounded yam "iyan" which is very popular with people in the yam-growing areas of Nigeria.

Yams are low in protein content and the small amount of protein in the tuber is largely lost when the yam is peeled before processing it into "iyan." Potato flakelets manufactured when protein is incorporated into mashed potatoes suggests that a protein-rich food product from yams is a possibility and would be desirable for development. Meals prepared from yams are usually low in protein although attempts are made to compensate for this deficiency by supplementing these meals with meat and vegetable stew. Incorporation of protein into the "mashed yam" envisaged would increase its nutritional quality as well as improving its drying characteristics, as has been done with potatoes.

Rather than using calcium caseinate or milk proteins which are not readily available in the yam growing areas, plant proteins may be used as additives. Soybean, cotton seed, or peanuts (ground nut) which are commonly cultivated in Nigeria are good and inexpensive sources of protein. Soybeans are grown widely in the Northern states of Nigeria where they are used mainly as cattle feed. Soybean protein is slightly inferior to animal proteins but it is the most desirable of all plant proteins. It contains substantial amounts of the essential amino acids and the glutamic acid content is particularly high. Obstacles to the general use of soybeans for human food products have been the bitter and objectionable odor of such products and the presence of anti-nutritional factors such as a trypsin inhibitor, a hemagglutin, saponin, a goitrogenic factor, anticoagulant factors, and some others *(9)*.

Removal or changing these unpalatable constituents is now possible through heating, soaking, or fermentation with yeast. There is, therefore, no obstacle to using soybean protein isolates in yam processing except, of course, transportation of the soybeans from the Northern States to the yam growing areas in the Southern States.

Cotton seed is another inexpensive source of the essential amino acids. Cotton is grown on the same plots as yams at the time when the yam plant sheds its leaves. Cotton seed is only slightly inferior to the soybean as a protein-containing product, being somewhat deficient in methionine and lysine. The slight lysine deficiency is aggravated by traditional heat treating techniques, but properly processed cotton seed offers an excellent source of protein material. Ironically, the protein-rich cotton seed is fed to goats or discarded as waste in these yam growing areas. On a very limited scale, cotton seed is fermented and made into "ogiri." The greatest problem with defatted cotton seed in areas of the world where it is recognized as a good source of protein is the presence of a toxic polyphenolic pigment, gossypol, which must be removed before it is consumed by monogastric animals including man. Gossypol is innocuous to ruminants such as goats, sheep, and cattle because the pre-digestion process in the rumen converts the gossypol into a nontoxic material before entering the true stomach.

However, edible-grade cotton seed flour can now be

[3]Eastman Chemical Co.

prepared by removing gossypol by several methods of which a fermentation process seems to be most effective. Microorganisms used in the process produce, as metabolic by-products, vitamins such as riboflavin, $B_6$, nicotinic acid, biotin, folic acid, and vitamin K. Hence, the fermentation increases the nutritional content of cotton seed. Cotton seed flour instead of milk proteins could be widely applicable for production of protein-rich "mashed" yam products.

A problem that needs attention in fortification of yam flour or "mashed yams" with protein is the nonenzymatic browning reaction (Maillard reaction). This could occur between the reducing sugars of yam and the added protein supplements during drum-drying processes. In the spray-drying process, heat contact with the product is short during drying and removal. Quality is more likely to be preserved as overheating is less likely. Proper study of the optimum temperature and conditions of drying is necessary so that availability of added protein is not reduced during drum-drying.

*Potato flour by spray drying*

Various ways to prepare powdered potatoes have been used in the past but the recently developed spray drying technique, in which the highest possible degree of natural potato flavor in the rehydrated product is retained, is worthy of note. Most of the flavor components of a potato are concentrated in the skin and in those zones of the potato adjacent to the skin. As a result, there have been attempts to remove only the outer peel of the potato before cooking and drying or even to process whole unpeeled potatoes. Disadvantages of this process are *(a)* off-color products because the browning precursors are also concentrated in or near the skin of the potato, *(b)* failure to separate the peel and other undesirable portions of the potato in a product which has an uneven texture and little consumer acceptability, and *(c)* such dehydrated products have poor shelf-life because of the fat in the dehydrated product.

In processes developed by Hollis and Borders *(8)* and Sienkiewicz and Hollis *(14)*, potato material containing a substantial portion of the peel is cooked under carefully controlled conditions. In this process, whole, raw potatoes are washed to remove field dirt, and subjected to carefully controlled pre-cooking conditions, after which the potato cells are conditioned for the rigorous treatment to which they are subjected during slurrying. After slurrying, imperfections are removed mechanically by screening.

Following mechanical separation of undesirable portions, the slurry is dewatered to remove large quantities of free and solubilized starch, soluble reducing sugars, and some of the proteins which have been solubilized. The dewatering process may be effected by centrifugation or horizontal vacuum filter. The resulting filter cake is then reslurried in an aqueous medium and additives such as methyl cellulose, an aerating agent to impart fluffiness, may be added. Emulsifiers (monoglycerides) which offset any pasty, gummy texture that might otherwise be produced in a reconstituted potato product are added. The re-slurried potatoes with additives are spray-dried using spray drying equipment with drying gas or ordinary heated air flowing co-current or counter-current to the slurry being dried. The temperature of spray-drying is critical. It must be such that scorching of potatoes does not occur. Too high a temperature might cause potato solids to "toast," i.e. develop a tan color and sometimes an off-odor and -flavor. Of course, too low a temperature will not remove sufficient moisture from the atomized re-slurry.

Processing of yams into flour and reconstituting this in boiling water to give "amala" has been a long practiced process in the home in yam-consuming areas of West Africa and it is still the chief means of processing the yam to spread its consumption over the year. However, it is a very inefficient, laborious, time-consuming, and uneconomical process, in that most of the raw yam is wasted during processing.

In this process, yam tubers, usually subvarieties of *D. rotundata* (white yam), are peeled, washed, and sliced and then sun-dried for several days. The sun-dried slices are crushed in a wooden mortar with a pestle and sieved. Coarse particles are returned to the mortar and again crushed and sieved. This re-cycling continues until the coarse particles are reduced to a minimum. The flour is then reconstituted in boiling water to give a brown, rather plastic dough which is consumed with vegetable stew, meat, and other condiments.

The mechanical processing of yam into a product which, on reconstitution, will give a meal similar to the traditional "amala" is very desirable and urgently needed. The spray-drying method described above and used for potatoes would lend itself to producing such a product. It is desirable to incorporate those portions of the yam tuber next to the skin in the powdered yam because, as in the potato, flavor components of the yam tuber are likely to be concentrated in the skin. Moreover, the small amount of protein contained in yam tubers is largely in the skin portions which are usually discarded as waste or sometimes fed to goats and sheep. An additional advantage of incorporating the skin portions of the yam tuber into yam flour is the high probability that vitamin C is retained in the product. It has been observed *(4)* that retention of ascorbic acid during cooking of yams is highest when the yam is unpeeled before cooking (Table 3).

However, no explanation is given for the high retention of ascorbic acid when the yam is fried in palm oil or baked. It is probable that the ascorbic acid of the red palm oil is incorporated into the fried or baked yams. Roasting is normally done without peeling and, therefore, high retention of vitamin C is to be expected.

A processing method which allows retention of the peel of the yam as has been done with potatoes should be explored in developing a nutritious new product from yams. The traditional method of producing yam flour results in a reconstituted product that varies in color from beige or cream-colored to dark brown (almost black). Too dark a brown color of the reconstituted flour (amala) is objectionable but a lighter brown color, close to that of scorched powdered milk is much more acceptable. It is likely that a spray-dried yam flour would yield a rehydrated product which is lighter in color than the "amala" which consumers are used to, but there is no doubt that such a rehydrated product would be acceptable.

*Freeze-drying method*

Freeze-drying of the whole fresh tuber would be an ideal and superior method for dehydrating yams. Freeze-drying of biological materials is gaining popularity as a means of food preservation and many workers are trying to explore its true potentialities for large scale use.

Drying of a substance from the frozen state called "freeze drying," sublimation drying," or "lyophilization" depends on creation and maintenance of a difference in water vapor pressure between the very dry immediate surroundings of a substance and the ice in the frozen interior of the substance *(17)*. In this process, water vapor is continuously transported away from the substance but ice in the substance never melts. As a result, surfaces are unable to shrink as drying proceeds. When the product is frozen, water is withdrawn from the highly hydrated colloids of the food substance, first by crystallization of pure ice and then, if the temperature is low enough, crystallization of the remaining more concentrated solution. Sublimation of water, the solid constituents being completely immobilized, leaves behind a light, microporous structure of substantially the same dimensions as the original piece. Reabsorption of water into this spongy material is not only very rapid, but is usually quite complete as well because little denaturation of colloid constituents takes place.

Dehydration of the whole yam tuber by freeze-drying so that the characteristics of the yam are retained after rehydration is worth trying on a laboratory scale. The freezing point of yam tissue, like that of most biological materials is somewhat below zero. Investigations *(3)* yielded values between −0.9 C to −1.4 C. The freezing points of the tissues of *D. alata* appear to lie in the upper part of the range. This is as expected since the water content is much higher than the water content of other species. The freezing points of the varieties of *D. rotundata* lie in the lower part of the range.

However, the high cost of freeze-drying would be a limiting factor in its application to large-scale dehydration of yams. It is estimated that freeze-drying costs about five to ten times that of conventional drying of foods. The cost is estimated to be 10 cents (slightly less than Nigerian 10 kobo) per pound of water removed. This estimate is based on 1965 figures *(6)*. With advancement in technology, the cost has, perhaps, been cut from the 1965 estimate. Although freeze-drying is a superior process of preservation for the future, at present it is unappealing economically.

## OTHER POSSIBLE NEW FOODS FROM YAM

New yam products similar to potato products are possible. For instance yam "nuts," similar to potato nuts, the production of which is now discontinued because some pieces contain hard, compact areas which are difficult to chew *(15)*, might be tried. A potato snack has been made from freshly cooked potatoes, potato starch, potato flour, vegetable oil, salt, and shortening *(13)*. This product has an appealing taste, crisp texture and light golden brown color. A similar yam product in which flavorings and seasoning materials such as onion, hot pepper, and perhaps "egunsi" from melon seed (*Citrullis vulgaris*) or "origi" obtained from fermented cotton seed and red palm oil would, no doubt, be appealing and well accepted.

## CONCLUSIONS

There are many possible products that could be developed from yams and the various methods for dehydrating potatoes could be adapted for drying yams, because there are similarities between the two tuberous crops. However, a well balanced program of fundamental and applied research is urgently called for to study the carbohydrate content of the various species of yams, changes in sugar content during storage, and the ratio of reducing to non-reducing sugars at various storage temperatures. It is also pertinent to investigate the cause of browning and blackening and factors contributing to the pigmentations of yams.

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