Review of soil fertility management for yam-based systems in west africa

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Abstract

The project *Poverty Alleviation and Enhanced Food Availability in West Africa through Improved Yam Technologies* proposed to improve yam production in five West African countries (Nigeria, Bénin, Togo, Ghana, Côte d'Ivoire) during the period from 2000 to 2003. A recognized need for productive, stable yam-based systems is the maintenance of soil fertility. Trials were initiated in each country on the fertilizer needs of yam and in several countries on improved fallows or leguminous intercrops. A review of information was also recommended with the objective of guiding future research. A search of all available literature was agreed, including sources with poor accessibility (grey literature) that might be available in NARS libraries.

Background

As background to this review, we assume that we are targeting intensified yam production systems. It is generally known that yam cannot be grown continuously on the same piece of land. It is commonly known that yam should be grown in the first year after clearing fallow vegetation. Gigou (1987) says that this is to avoid weed competition for nutrients, moisture, and light. This is a major problem during the first 3 months of yam growth, which is slow. In addition, most writers imply that yam is the first crop after fallow because of nutritional requirements. "Yams are considered a demanding crop, so they come first in the rotation cycle in most traditional yam-based farming systems. They are thus the first to benefit from the restoration of the soil's fertility" (Degras 1993). But before drawing firm conclusions we must first be clear on what we mean by soil fertility in the case of yam. Soil fertility for yam in this review is taken to mean:

i. Adequate nutrient supply to the growing plant
ii. Adequate soil moisture retention
iii. A loose soil structure for good root expansion

A first point at which to learn about sustainable yam production is to document yields in continuous yam production trials. For example, in the savanna zone of southern Burkina Faso, Somé et al (1995) observed that the yield decline from one year to the next was dramatic (Table 1) in spite of the fact that the second year had better rainfall. Also Odurukwe and Oji (1981) observed that the fresh tuber yield at Umudike in southeastern Nigeria declined even with high organic and inorganic nutrient amendments. This suggests that an important cause of yield decline is not related to soil fertility but may be due to pests and weeds. Yeboua (1990) demonstrated that yield decline could be partially prevented by the application of fertilizers.

The effect of the duration of previous fallow on yam yield also suggests that yam depends on undegraded soil conditions. Watson and Goldsworthy (1964) grew yam after several durations of fallow and observed a strong positive correlation between the length of fallow and yam yield (Table 2). Unfortunately there are few studies of this kind that have been documented. Another indicator of yam's dependence on good soil conditions is the effect of the duration of continuous cropping on yam yield. Djokoto and Stephens (1961a) found that average yields of yam at Ejura were 9.1 t/ha in the first two years of continuous cropping and 7.2 t/ha in the third and fourth years. In contrast, average yam yields in Tamale and Nyankpala were higher, 7 to 9 years after fallow, than in the first years. This is probably due to the soil improving effects of the mineral and organic fertilizers applied. Similar information can be gathered from studies of the effect of the length of previous fallow periods.

Degras (1993) states that the length of cropping and fallow periods depends on the inherent soil fertility and nutrient amendments that are available. For example, alluvial soils allow more years of yam cropping before a switch to other crops or fallow. Also, fertilizer use may allow more years of cultivation before fallow is needed.

This review focuses on issues to be taken into account in recommending fertilizer applications and organic matter maintenance systems for sustainable yam cropping. The collaborators agreed on elements of an outline that are reflected in the contents of this document. They looked for relevant information from their countries. For further information, all country reports are available from IITA.

Fertilizer issues

Current use of fertilizer on yam in the different countries. There is little information on fertilizer use in yam production. Fertilizer use was heavily promoted in Nigeria in the 1970s and therefore it can be expected that fertilizer use is highest there. In a survey conducted in 1981 by Unama et al (1985) in southeastern Nigeria, 55% of farmers surveyed applied fertilizers to their crops. Of those farmers, about 78% applied the recommended rates. Major crops fertilized were cassava (96% of the farmers who used fertilizer), maize (72%), yam (64%), and vegetables (42%). Thus approximately 35% of farmers surveyed applied fertilizer to yam. At the same time in the middle belt of Nigeria, there was virtually no fertilizer application in yam production. It is not mentioned at all in a comprehensive survey by Diehl and Winch (1979).

A more recent survey in the western middle belt of Nigeria was conducted in the mid-1990s by Manyong et al (2001). They found that inorganic fertilizer was used on 27% on men's yam fields and on 34% of women's yam fields. Thus, the results of the two surveys are similar. There appears to be slightly less use of fertilizer in the middle belt because human population density is much lower there and land is not as scarce as in southeastern Nigeria. Organic amendments were applied to 11% of men's fields and 19% of women's fields in the middle belt study.

Another recent survey in the East-Central section of the yam-producing belt in Nigeria by Amegbeto et al (2003) found that 60% of farmers use fertilizer for yam production. The survey went further to examine the intensity of use by those farmers. It provided evidence of intensification and sedentarization of yam cultivation by older farmers. Other variables that were closely linked to fertilizer use were the size of the farmer's yam area, the number of other crops on which fertilizer is used, and whether or not some yam is sold (market orientation).

Fertilizer use for yam in Bénin appears to be extremely low. It was not mentioned in studies of yams production in Bénin by Dumont (1985), Bruntrup and Kougba (1991), Vernier (2001) found that only 4% of yam producers applied fertilizer directly to their yam in a survey of several villages in Bénin. However, most farmers applied fertilizer to their maize and cotton, which were grown in rotation with yam.

Current fertilizer recommendations for yam in each country. There are many publications of fertilizer response trials, especially from Nigeria. Almost every trial resulted in a new recommendation for yam fertilizer application. A summary of these trials and recommendations is included (Annex 1). Some of them are based on a soil type and others purport to be valid for an agroecological zone. But important information such as field history, dominant fallow vegetation, and soil properties are rarely included in the reports.

In Bénin and Togo, there is one blanket recommendation for yam. This is a dangerous situation, which may cause some farmers to lose money. In Côte d'Ivoire, there are different recommendations for different species (Annex 2), but the recommendations are again country-wide. In Nigeria, there are many recommendations. Sometimes, this is justified in the case of different ecological zones or soil types. But sometimes different recommendations are given, even for the same zones. This suggests that the trials were conducted under variable conditions by different authors and those conditions were not very well described. Also, some of these recommendations emanate from a limited number of trials on a limited number of sites in a limited number of years. Thus, they are only approximations. Field history is rarely mentioned in the reports, but field history can change drastically the recommendation for a given crop on a given type of soil. For example, yam grown on a field that is recently cleared from fallow is not likely to respond to fertilizer because soil organic matter is high and adequate nutrients may be stored in the mineral and organic fractions of the soil. After several years of cropping, the same cultivar may respond to

N applications.

In modem agriculture, fertilizer amendments are based on soil testing or on field history combined with soil type. But soil properties are mentioned in few of the reports of fertilizer response. Another method of calculating fertilizer needs may be to estimate the exports of nutrients in harvested yam tubers. In addition, the appearance of deficiency symptoms can guide investment in fertilizer.

Nutrient deficiency symptoms on yam. It is recognized that images of nutrient deficiency symptoms could be used to guide decisions on where and when to apply fertilizer. Descriptions of nutrient deficiencies were recorded for *D. rotundata* by Gaztambide and Cibes (1975) and are presented below as taken from Degras (1993). O'Sullivan et al (no date) have also described deficiency symptoms in *D. alata*.

Nitrogen: Very small leaves, light green or yellowish at first, then drying out from the tip to the edges before falling off. The leaves that grow back are thin, translucent, contain anthocyanins and do not fall.
Phosphorus: Purple or violet leaves when young, and dark, shiny green leaves when mature; senescence is marked by scattered yellow to light brown then dark brown leaf areas, then the area between becomes yellow; the leaves fall starting from the bottom to the top.

Potassium: Small, round, brownish spots appear, then the leaves roll up, afterwards, the spots coalesce especially at the margins; they appear burnt and necrotic, with a yellow background; leaf abscission.

Calcium: The leaf is small and leathery, the older ones are mottled and yellow; at the end they become necrotic along the main vein on the underside of the leaf.

Systematic images of symptoms do not yet exist for yam although the paper by Gaztambide and Cibes (1975) includes some images. It is clear that images of nutrient deficiencies should be made available to development projects. In the absence of this, maize nutrient deficiency symptoms are very clear (Figure 1) and can be used to indicate the nutrient status of soil for the eventual application of fertilizer to yam.

Most commonly limiting nutrients. Researchers should attempt to clarify the nutrient elements that are most often limiting to the yam yield. This knowledge can be used by farmers to economise on fertilizer. For example, if yam rarely responds to nitrogen (N) additions, and the applied N leaches from the soil before a crop can be grown after yam, then the investment in N fertilizer will have been wasted. Identification of limiting nutrients can best be done by using missing nutrient techniques or factorial experiments in which the effects of single nutrient applications can be isolated. The application of combined fertilizers can not help to achieve this. These trials can be done in nutrient solution, in pots, or in the field. Each kind of trial has its advantages and disadvantages.

The most limiting nutrient for yam growth in nutrient solution was shown by Gaztambide and Cibes (1975) to be N. Biomass of tubers and aerial apparatus without N was less than 1% of biomass with a complete nutrient solution. Phosphorus (10%) followed N, calcium (15%), potassium (25%), and sulfur (30%). This may not necessarily be the case in the field because the soil provides some part of the required nutrition.

Experience from many years ago gave useful indications of fertilizer responses. For example, trials in eastern Nigeria from 1947 to 1951 showed a consistently positive effect of N application and a lesser response to K (Irving 1956). The same author found that response to P was rare and occurred only when the previous fallow was dominated by grasses. Unfortunately, soil nutrient characteristics are not included in the paper. The results of a large fertilizer experiment conducted in Ghana also suggested that P and K were not needed in the savanna, but only in the forest. For Togo, Ghana, and western Nigeria, the FFHC (1965) confirmed the need for N in all cases, while the need for P and K was less clear. A relatively minor attempt to assess yam yield response to individual nutrients was synthesized by Djokoto and Stephens (1961a; 1961b) in central and northern Ghana. The highest frequency of yam yield response was achieved from P application. There was never a response to K. However, it must be noted that the results were confounded by rotation effects with other crops. In Côte d'Ivoire, Chabalier (1980) observed a clear response to N but it is not clear how the trial was conducted and where.

More recent studies give a bit more clarity, especially where soil properties are also reported. Kayode (1985) worked in four different fields over a 4-year period in southwestern Nigeria and found that *D. rotundata* did not respond to N in the environments where soil organic matter (SOM) was 4.6 or 5.6% (Table 3). But in the environments where SOM was 1.7 and 0.9%, a significant yield increase of 12.5% was observed with 35 kg N/ha. In those trials, there was no effect of P and K application where P was 8 mg/kg or more and exchangeable K was 0.15 meq/100 g or more (Table 4). These results can give an idea of critical nutrient levels. In northern Ghana, Koli (1973) observed substantial responses of yam to N application on fields where SOM was 0.8% or below (Table 3). Exchangeable K was 0.29 meq/100 g and there was no response to K additions. Available P was 13.7 mg/kg and response to P was substantial.

In a trial at IITA in southwestern Nigeria, Kpeglo et al (1981) achieved a maximum yield of 42.6 t/ha with 45 kg N/ha and 30 kg K/ha. The same fertilizer rate gave the highest marketable tuber yield of 38.4 t/ha. Yield reduction was 7.5 t/ha from withholding N and 7.9 t/ha from withholding K. Soil properties were not reported in the paper. Lyonga (1981) also recorded significant responses in the highlands of Cameroon to N alone, K alone, NP and NK. The ratio of extra return to cost averaged 5.2 for N alone, 5.0 for K alone, 3.5 for NP, and 3.7 for NK. The soil properties are not given.

In Togo, there was little research on soil fertility for yam before 1988. One trial was conducted in 1990 and 1991 by the Institut National des Cultures Vivrières (INCV) at Sotouboua on a *sol ferrugineux tropical*. There was no response to N in these trials in which yield potential seems to be limited to approximately 12 t/ha. Application of K increased yield and application of P increased tuber size and commercial yield (tubers larger than 1.5 kg). Based on this and the good food quality (for pounded yam), the author recommended 50 kg P_20_5 and 60 kg K_2O/ha. But this was not validated in other years or at other sites.

In summary, there is substantial variability in the results over time and space. It is expected that over time, the probability of the response of yam to fertilizer will increase as soils become more depleted. This was noted by Irving (1956) and illustrated by the results of Kayode (1985). Since dominant vegetation is an indicator of soil quality, this could also be used. Other trends may be related to soil types on different parent material. For example, in Ghana and Nigeria, the predominant soils are from sedimentary rocks in forested regions and from igneous and metamorphic rocks in the savanna regions, which usually contain adequate K. So response to K would be less likely in the savanna regions.

Strategy for the development of fertilizer recommendations. The strategy for fertilizer recommendations is to generate the maximum economic return. Economic return depends on the cost of the fertilizer and the value of the increased yield. The problem faced by the farmer is to foresee the response (yield increase) from the application of a given amount of fertilizer. Certain tools can be used to guide a farmer's fertilization program. Tools for guiding fertilisation include the following.

- Nutrient deficiency symptoms: If nutrient deficiency symptoms are observed, then it is highly probable that there will be an economically justifiable response to fertilizer application. However, if they are not observed, there may still be an economic response to nutrient additions. So the lack of symptoms does not indicate that supplemenatary nutrients are not needed.
- Correlations between soil types and nutrient deficiencies: Some soil types are known to be deficient in certain nutrients. For example, the sedimentary soils of the rainforest zone of southern and eastern Nigeria (Obigbesan, 1981) and southern Bénin and Togo are known to be low in K and responses to K are more likely. On the other hand, the soils of the Guinea savanna zone of West Africa generally have adequate K reserves and therefore a low probability of response to K unless the soils have been continuously cropped over a long period. Soils of semi-arid zones are known to be low in SOM and hence in N. They would be expected to respond to N application.
- Fertilizer response trials: If a crop responds to the addition of a nutrient, this tells us that the nutrient is limiting yield under the conditions of the trial. But it does not mean that this nutrient will be required under all conditions. From this result we need to judge how far to extrapolate the need to apply fertilizer. A large number of response trials are needed over years with varying weather conditions and on different sites that are well described.
- Correlations between field history or dominant vegetation and fertilizer response: The probablility of a response increases with the duration of cropping. For example, fields recently brought out of forest fallow are not likely to respond to N. But crops may respond

to N after grass fallow in the forest or in the savanna zone. Fallow may not bring the soil fertility to a level that is sufficient for high yam yields and the quality of the fallow vegetation can be linked to fertilizer response. Irving (1956) noted that a response to P was observed only when the fallow vegetation was dominated by grasses. He also noted that response to K was more likely where the bush cover was poor. Therefore, fertilizer response trials should be conducted on field sites with different cropping or fallow histories and the results must be synthesized, taking into account the different histories. Fallow vegetation is a good indicator of the fertility of the soil. The major type of vegetation (trees, bushes, grasses) should be described, as well as the dominant species if there are only one or two of them (for example, *Chromolaena odorata*, *Imperata cylindrica*, *Andropogon guyanensis*, etc.)

- Correlations between soil characteristics and fertilizer response: The response of a crop to fertilizer addition also depends on the nutrient levels in the soil. If there are sufficient nutrients in the soil to achieve potential yield, then there will be no response to fertilizer. For a farmer, it would be an ideal situation to know the nutrient status of the soil. However, fertilizer recommendations based on soil testing are not currently used in tropical Africa, as soil testing is very expensive and there are insufficient fertilizer trials in which soil properties are known. In many places, fertilizer application is guided by soil nutrient concentrations compared with the critical level, which can be defined as the soil nutrient level above which the crop is not likely to respond to the addition of that particular nutrient.
- Yield potential: Higher yield potential (due to high solar radiation, adequate rainfall, irrigation, good protection from pests and diseases, etc.) increases the probability of a response to fertilizer. This is because, if yield potential is high, then the soil may not be able to supply sufficient nutrients as rapidly as they are required by the crop. For example, in Trinidad, Van der Zaag et al. (1980) showed that varieties (and species) with higher potential yield have a higher demand for P. If yield potential is low for some reason other than nutrient limitations, then the yield of a crop is not likely to be increased by fertilizer. Yield potential is most influenced by climate (solar radiation, drought, flooding). In root or tuber crops such as yam, the response is also influenced by the soil's physical properties. For example, Kang and Wilson (1981) found that the response of *D. rotundata* to fertilizer depended on the mound size. With large mounds (30 cm in height) the response to fertilizer was 16%. Much smaller responses were obtained with mound heights of 24 cm (6%) and 13 cm (7%). Without mounding, the response to fertilizer was slightly negative.

Clearly, there are several tools for the development of fertilizer recommendations. Each requires information of different kinds. In the absence of observed nutrient deficiencies and adequate fertilizer response studies, there are some simple approaches:

- Replace nutrients exported in harvest: This approach is biologically sustainable in the long term but it may not be justified in the short term if the soil actually supplies all of the nutrients needed by the crop.
- Underestimate fertilizer needs: This approach reduces risk. As shown in Figure 1 (scenario 'C'), the greatest response of crops to fertilizer is generally to the first increment. Thus, a solution in the absence of clear information is to apply small amounts carefully near the plant at a time when the plant can absorb the nutrients.

Lack of response by a crop to an added nutrient generally has two causes. The first is that the nutrient is supplied in sufficient quantity and rapidly enough to satisfy the crop (shown as scenario 'A' in Figure 1). This explains why yam grown immediately after a long forest fallow is not likely to respond to fertilizer. Onwueme and Charles (1994) suggest that yam rarely responds to P because the soils on which yam is grown are rich in P, but also because mycorrhizae associated with yam roots facilitate the absorption of P.

The second case is where the soil's physical properties are highly degraded and the plant cannot take advantage of the additional nutrients. This is shown in Figure 1 as scenario 'B'. The crop roots cannot effectively absorb the fertilizer that is supplied.

Nutrient exports in yam yields. In the absence of clear production functions, due to a dearth of well characterized nutrient response trials, approximations can be made by combining information on the nutrient contents of tubers, average yields or target yields, internal nutrient requirements of the yam crop, and estimates of nutrient supply from the soil. The nutrient content of tubers can be used to estimate the amounts of nutrients exported in the harvest. One possible strategy for nutrient management is for additions to replace exported nutrients. The results of several studies are collated in Table 5. Note that the estimates in fresh tubers can be compared to those from dry tubers by multiplying by 3, assuming 33% moisture in tubers. A synthesis of the data reveals that exports per tonne of fresh tubers are typically 3 to 5 kg N, 0.3 to 0.5 kg P, and 3 to 5 kg K.

Using the approach of replacing exported nutrients, a farmer would multiply the yield by the nutrient content. For example, the export of N by a 10 t/ha tuber yield can be estimated at 40 kg/ha (80 kg/ha for 20 t/ha; 120 kg/ha for 30 t/ha). This does not take into account other losses of N during the growing season. The major cause of loss of N would be leaching and would occur during heavy rains when the soil is saturated. This would be aggravated if the crop is not yet well established.

Some improvement in the estimated need for fertilizer can be achieved if the internal requirement is known. The internal nutrient requirement is the amount of nutrient in the entire crop biomass, which produces a particular harvestable product. Sanchez (1976) has compiled this information for many crops, but not for yam. The internal requirement includes the nutrient content of the harvested product (tubers in this case) and the rest of the plant. It is used to estimate nutrient balances and nutrient needs. Estimates of aboveground yam biomass are rarely collected and estimates of litter fall before tuber harvest do not exist. One study that can contribute to information on the internal nutrient requirements of yam was reported by Irizarry and Rivera (1985) from Puerto Rico (Table 6). It shows that the harvest index of dry matter and most nutrients is around 65 to 85% except for calcium, which is around 20%. The N harvest index was 71.4%. This means that for a harvest of 30 t/ha, there would be 120 kg N in the tubers and 120 / 0.714 = 168 kg N/ha in the entire crop. There should be more estimates of the nutrient harvest index in yam. Practices that influence the source and sink relationships (e.g., staking, soil preparation) can influence the partitioning of nutrients in the plant and change the nutrient harvest index.

In addition to internal crop requirements, it is necessary to have an estimate of the supply of nutrient by the soil. The difference is the amount that should be absorbed by the crop from fertilizer. However, it should be noted that not all fertilizer is absorbed by a crop. The exact estimate of fertilizer addition takes into the fraction of nutrient that is taken up by the crop. This is often called fertilizer recovery or nutrient uptake efficiency.

Soil and plant critical nutrient levels. Leaf and soil nutrient levels are used to guide fertilizer applications to crops in many countries. For leaf critical levels it is first necessary to know which plant organs to sample and when to sample them. This is based on intensive research to study nutrient concentrations in different plant parts over time. Ideally, this is also related to crop yield and it is done in many environments. The data of lrizarry and Rivera (1985) suggest that the most appropriate time to determine the nutritional status of yam is about 5 months after planting when near maximum growth rates of leaves and vines occur. In one study in southwestern Nigeria, the nutrient content of *D. rotundata* lamina was found to be 3.20-3.45% N, 0.28-0.30% P, 2.20-2.50% K, 0.45-0.70% Ca, and 0.27-0.37% Mg at the peak period of nutrient supply (Obigbesan and Agboola 1978). The authors suggested that the leaf lamina is more appropriate for N and P diagnosis while the petiole is more satisfactory for diagnosis of K deficiency. This was based on their observation of high concentrations and rapid changes during the season. However, it was not based on comparison amongst differentially fertilized plots. They further suggest the use of fully mature but not senescent top leaves on the fourth branch on each main stem and that sampling should be at about 10 a.m. Janine (1985) observed a strong correlation between leaf K concentration and yam yield in southern Côte d'lvoire. Budelman (1989a) also observed a strong correlation at Adiopodoume, near Abidjan.

Regarding soil critical levels, various authors emphasize that responses are likely on soils containing less than 0.1% N, less than 10 ppm available P (Bray-1) and less than 0.15 meq/100 g of exchangeable K. The critical K level for cassava is also approximately 0.15 meq/100 g (Howeler; Kang). On Alfisols at Otobi in the southern Guinea savanna, Ohiri (1990) obtained the highest tuber yield consistently in 1985 and 1989 with the application of 90 kg N, 10 kg P and P (<15 mg/kg) but medium in K (0.20-0.30 mg/100g).

Fertilizer management for yam production. The key to good fertilizer management is making the maximum amount of nutrients available to the crop. Possible loss of nutrients must be avoided and this is best done with the appropriate timing of application.

The time of application depends how susceptible the nutrient is to loss. P is immobile and can be applied any time before the plant is established. N is very mobile and and is rapidly leached during heavy rains when the soil is saturated. K is less mobile but can be managed like N. These nutrients should be applied a few weeks before the period of maximum growth (Obigbesan 1981). It may be worthwhile to apply part of the N and K at emergence and the rest when the plant is growing vigorously, but the return on this added labour is not known.

In addition to the time of application, the placement of fertilizer is very important. Because P is immobile, it should ideally be incorporated into the soil at the time of mounding so that it comes into contact with many roots. But N and K should be applied close enough to the plant to provide good accessibility to the roots. However, one must be aware that spot or band placement too close to the plant can result in high concentrations that can damage plant tissues. Onwueme and Charles (1994) summarized the usual recommendations for fertilizer placement as follows. On mounds: Most authors apply the fertilizer in a circle 15 cm from the yam plant at a depth of 3 to 5 cm. But it could also be spot placed.

On ridges: The fertilizer is applied in a band 10 cm from the centre of the ridge.

In addition to the above considerations, the number of fertilizer application operations that are needed must be taken into account. On very small plots, it would be justified to apply P while mounding and to apply N and K after emergence and during vigorous growth (i.e., three different operations), but this might not be justified on a large-scale farm where multiple applications would be too costly. Applied P also continues to have an important effect in subsequent years. Therefore, as a compromise solution, complex fertilizer can be applied after germination. This is reasonable because P is rarely the limiting nutrient.

Researchers have studied the effect of the date of application with respect to the date of planting. For example, Chebalier (1980) found that N application 3 months after planting resulted in a higher yield than application 1.5 months after planting. However, fertilizer should be applied only to mounds on which plants are growing. And it is only by observing the plants' growth that one can judge if the plant is nearing its period of rapid nutrient uptake. The INRAB fiche technique recommends that fertilizer be applied one month after germination and this appears to be a reasonable recommendation.

Effect of fertilizer application on yam quality. Farmers often do not apply fertilizer to yam because they perceive that it will result in tubers of reduced quality for storage and for consumption. For example, the INRAB (1995) technical guide states that excess N results in tubers with high water content that do not store well. The use of inorganic fertilizer is strongly believed by farmers to be a major factor causing the rot of yam tubers in storage (Chukwu et al 2000, unpublished draft). As a consequence, some yam farmers refuse to use inorganic fertilizer in the production of seed yams or those meant to be stored beyond 6 months after harvest (Chukwu et al, 2000, unpublished draft). According to Vernier et al (2000) the problem of fertilizer application reducing quality appears to be true for the first harvest of early, double harvest types but it is not true for the second harvest of the double harvest types, or for late varieties, or for *D. alata*.

Starch content: Results from a fertilizer trial on Alfisols of southwestern Nigeria using a factorial combination of N, P, and K (Kayode 1985) revealed that neither nutrient had any significant effect on the starch content of yam. Umanah (1973) and Adeniji (1998) found the same negative effect. For Treche and Guion (1983), the ratio of amylase to amylopectin increases with N application but the significance of this finding is not obvious. Some authors observe that N application increases starch content, especially in the first harvest (Okpon and Aduayi, 1988). Obigbesan (1973) found increased starch contents of yam tuber with K fertilizer. Maximum starch content for *D. esculenta* were obtained with 40 kg N/ha and 120 kg K_20/ha (Singh et al. 1973).

Dry matter: According to Vernier et al (2000) and Obigbesan (1973), excess N appears to increase tuber water content while K appears to reduce water content and improve storage. This is fairly well documented for tuber crops in general (Treche, thesis). However, Kayode (1985) demonstrated slight increases in tuber dry matter from N application and slight decreases from P and K application for Enyi (1972), Hedge (1981) and Singh et al. (1973). Contrary to this, Treche and Guion (1983) found dry matter to decrease with N application. Adeniji (1998) observed no effect of fertilization on the dry matter content of yam.

Browning: Etereje et al (1990) found that the browning potential of the surfaces of cut tubers of *D. rotundata* has been observed to be significantly higher in yam tubers produced under fertilizer application. This browning was supposed to be non-enzymatic.

Weight loss in storage: Kpeglo et al (1985) found no effect of fertilizer rates on weight loss in storage. Umanah (1973) and Azih (1976) had similar results. There are two kinds of loss in storage. One is the loss from damage during harvest and transport and the other is physological loss (respiration). A trial conducted in Côte d'lvoire assessed the influence of chemical fertilization with NPK (75-54-94) on storage losses of different varieties of yam (two *D. alata* and one belonging to *D. cayenensis-rotundata*) (Dumont et al 1997). The authors observed that fertilisation resulted in more storage loss from both mechanisms. They also note that the importance is probably underestimated because farmers select out damaged tubers before storing. Physiological losses were greater for *D. cayenensis-rotundata* than for *D. alata*.

Sprouting: Kpeglo et al (1981) found that N application increased sprouting in storage and high K application reduced sprouting. The same results were noted by Obigbesan and Adesiyan (1981). However, the statistical treatment of the data is not clearly described and the fertilizer effects were significant only in one out of two years of observation.

Quality of pounded yam: Obigbesan (1993) reported that farmers in the Kabba area of southwestern Nigeria complained that yam grown with 125 kg/ha of ammonium sulphate fertilizer darkens on cooking. As a consequence, many farmers were reported to refuse to apply this fertilizer to yam for fear that it would impair the quality of pounded yam. In a survey of the root crop belt of Nigeria (Ohiri et al. 1996) reported that the majority of farmers (70%) interviewed in southwestern Nigeria, believed that fertilizer reduced the pounding quality of yam. Vernier et al. (2000) found that fertilizer application (200 kg/ha of 14-23-14-5-1 N-P-K-S-B) had a negative effect on the elasticity and on the taste of 'Baniwoure' (*D. rotundata*; late maturing) and no effect on 'Singo' (*D. rotundata*; late maturing; many small tubers). Adeniji (1998) found that N fertilizer alone reduced the acceptability of pounded yam from a *D. rotundata* variety while NPK slightly improved it. Adeniji (1998) found that fertilizer application affected the color and elasticity of pounded yam but not the taste.

Because of the concern for yam quality, Hydrochem in Bénin has already proposed a fertilizer formulation for cassava and yam in which K_2O concentration is twice that of N concentration, stating that this is done to reduce the risk of root rots. The formulation is 13-9-27-5S-4MgO.

Effect of fertilizer application on nematode infestation. It is known that nematode populations are affected by soil properties (Cadet and Thioulouse, 1998). Therefore, it might be expected that fertilizer application would influence nematode populations. Several studies have been conducted on the effect of fertilizer on nematode populations, especially *Scutellonema bradys* (Steiner & Lehew) Andrassy For example, a reduction of *S. bradys* was demonstrated by Adesiyan and Adeniji (1976) when yam was amended with a high level of N-P-K fertilizer (Coyne and Baimey, personal communication, 2002). However, N alone on D. rotundata increased the fraction of infested tubers (Luc et al 1993). In the same study, P application mitigated the effect of N on tuber infestation. These results corroborate the observations by farmers recorded by Adesiyan and Adeniji (1976) (cited by Luc et al 1993). Obigbesan and Adesiyan (1981) also report that yam fertilizered with N alone without P and K produce poor quality tubers which accumulate a larger number of dry rot nematodes.

The application of N P K and Nemagon suppresed *S. bradys*, but Nemagon reduces significantly the yield of *D. alata* (Adeniji 1977). The use of organic manure gives higher yields and considerably reduces the density of nematodes. Wood ash increased yield but was ineffective in reducing nematode densities (Adeniji 1977).

Organic matter as sources of nutrients. Janine (1985) found good responses to organic fertilization but there are not enough details to know whether it was because of the nutrient supply or because of the improvement of soil properties with consequent moisture or nutrient retention.

Application of organic nutrient sources such as cow dung ensures a more balanced nutrition and less probability of the negative effects on quality. Ohiri and Chukwu (1991) found that application of 4.0 t/ha of cow dung could replace 50% of the inorganic fertilizer requirements for yam.

Organic matter management

Soil organic matter levels needed for yam production. A limited review of research results led Degras (1993) to postulate a total N concentration of 0.1% as sufficient to render forest soils adequately fertile for yam cultivation. This corresponds to about 1.2 to 1.5% organic carbon and 2 to 2.5% SOM. Djokoto and Stephens (1961) found yam yield to be positively correlated with soil organic carbon (r=0.81) in five sites in Ghana. Kayode (1985) also observed the response of yam to N fertilizer to be correlated with SOM content (Figure 2).

Assuming a target of 2% SOM, how can this be achieved? de Ridder and van Keulen (1990) give guidelines for simple calculations of organic matter (OM). First, it is necessary to calculate the amount of OM/ha so that it can be compared with the amounts available in various fallow or cropping systems. For example, assuming an SOM content of 1% and a soil bulk density of 1.4 g/cc, one hectare to 30 cm depth contains 42 t (1 g SOM/100 g soil x 30 cm x 10,000 cm x 10,000 cm x 1.4 g/cm x 1 tonne/I ,000,000 g) of SOM. Then, it is necessary to calculate the amount of additional OM needed to compensate for the decomposition of the initial SOM content. Assuming an annual rate of loss of SOM of 4%/year, 1.68 t/ha must be added just to maintain SOM. Finally, it is possible to estimate in a similar manner that in order to increase SOM from 1% to 2%, 42 t/ha of OM would be needed.

Once the target SOM content is achieved, a similar calculation suggests that annual additions of 3.36 t/ha (2 x 1.68 t/ha) would be needed to maintain this level.

Potential of improved fallow systems to contribute to soil organic matter. A suggestion for yam research and development by Degras (1993) was to experiment with legumes in yam production systems as soil conditioners, sources of N, organic matter, and for weed control (p.347). The most studied systems of organic matter production using legumes are based on herbaceous legumes and woody perennials. We consider *Gliricida sepium* as one candidate woody system and *Mucuna* and *Pueraria* as herbaceous legume systems.

Gliricidia sepium live staking system. The *Gliricidia sepium* live staking system is one promising niche for agroforestry because yam responds well to staking and requires OM inputs. Furthermore, *Gliricidia* has a canopy that allows more light transmission than most other trees because of its 'open architecture' (Budelman 1990). There are several studies of alley cropping with *Gliricidia* in various sites in humid and subhumid West and Central Africa that can provide estimates of *Gliricida* pruning dry matter (Table 7). In some trials, total prunings were measured, while in others, leaf and stem biomass were measured separately. Kang and Van den Beldt (1990) reported production of total dry matter of *Gliricidia* prunings of 5.5 Mg/ha from five prunings of trees spaced 4 x 0.5 m (5 000 trees/ha) on an Alfisol in southwestern Nigeria. Otu and Agboola (1994) estimated pruning dry matter of 8.5 Mg/ha with three prunings in the second year after *G. sepium* planting in southwestern Nigeria at a density of 2500 plants/ha.

Since most of the nutrients are found in the leaves, we tried to find estimates of the proportions of leaves and stems in prunings of *G. sepium*. Small stems are sometimes measured with the leaves since they are also applied as mulch, while large stems are often taken away for firewood. However, some researchers may strip leaves from the small stems and weigh the latter together with large stems. Fagbola et al (1995) found that one-third of the dry matter from prunings of *G. sepium* was composed of leaves and two- thirds consisted of stems. Tossah et al. (1995) reported a relation of approximately 60% leaves and 40% stems. Their objective was to identify tree species for the production of mulch and firewood and small stems were weighed together with leaves, thus explaining their high estimate of leaf production. It appears that leaves and twigs form approximately 50% of *Gliricidia* prunings dry matter. From all of the results we can estimate average production of *G. sepium* mulch (leaves and twigs) of 3 Mg/ha, with a range of 1.5 to 4.5 Mg/ha (Table 7).

Herbaceous legume rotation systems. For *Mucuna*, a typical dry matter accumulation is approximately 5 to 6 t/ha (Table 8) although it can range from 1 to 12 t/ha depending on soil properties, drought, and waterlogging. This dry matter must be protected from fire and from bowsing animals if it is to contribute to SOM. Amounts of *Pueraria* dry matter are similar. Tian et al. (1999) measured 7.6 t/ha above ground and and 9.2 t/ha including roots. In the same trial, *Chomolaena odorata* accumulated 7.8 and 8.8 t/ha, respectively. In southern Côte d'lvoire, Autfray and Gbaka Tchetche (1998) found that *Pueraria* fallow usually produced more than 10 t/ha of mulch, slightly more than *Chromolaena odorata*.

The use of *Pueraria* has been particularly attractive after the experience in central Côte d'lvoire of Charpentier et al (1999) in which yam yield without soil tillage was approximately 17 t/ha after one year of *Pueraria* fallow compared with 8.9 t/ha on mounds after natural fallow, In the next cycle, yam after *Pueraria* without mounds produced 3.5 t/ha and the control produced no yield, due to unfavorable rainfall. Measurements of water infiltration under analogous conditions showed that the rate was doubled by a 1-year *Pueraria* fallow (Charpentier et al. 1999). A trial in the forest zone (Tene 1997) confirmed that yield of yam without tillage was slightly increased (13%) for Dcr 'Bete Bete' and substantially increased (56 %) for Da 'Florido' (Autfray and Gbaka Tchetche 1998). At a different site (Gabia, 1997), the same authors observed a decrease in bulk density under 18 months of *Pueraria* fallow of approximately 13%.

Table 1. Yield of yam in the same field over time in West Africa.

Source	AEZ; country	Year 1	Year 2	Year 3	Year 4
1	Humid; Nigeria	23.6	16.0	5.9	13.0
2	Humid; Côte d'lvoire; + fertilizer	15.7	-	-	11.1
2	Humid; Côte d'lvoire; - fertilizer	17.6	-	-	7.6
3	Sub-humid; Burkina Faso	13.0	7.2		

Sources: 1 = Odurukwe and Oji (1981); 2 = Yeboua (1990); 3 = Somé et al (1995)

Table 2. Yield of yam as a function of length of previous fallow period in central Nigeria.

Fallow length (years)	Fresh tuber yield (t/ha)
1-2	5.7
3	9.7
4	10.8

Table 3. Response of yam to N application and soil organic matter concentration.

Author	Year	Yield without fert	Response (t/ha)	SOM (%)
Kayode (1985)	1978	15.95	0.37	5.6
	1979	17.0	0.96	4.6
	1980	15.6	1.83	1.7
	1981	16.5	3.52	0.9
Koli (1973)	1970	13.8	2.7	0.72
	1971	20.8	2.3	0.83

Table 4. Response of yam to P application and available P (Bray-1) concentration

Author	Year	Yield without fert	Response (t/ha)	Bray-1 P
Kayode (1985)	1978	16.0	0.22	7.0
	1979	17.8	None	8.0
	1980	17.7	None	10.1
	1981	19.2	None	11.5
Koli (1973)	1970	13.5	1.6	13.7
	1971	20.8	1.3	13.7

Table 5. Range of nutrients in kg/Mg in dry and fresh yam tubers.

Estimate	State of tubers	N	P	K
Obigbesan and Agboola (1978)	Dry	14.2	1.9	17.9
Ferguson et al (1980)	Dry	13.7	1.3	11.6
Budelman (1989)	Dry	10.2	1.4	9.6
Sobulo (1972)	Fresh	4.6	0.33	2.9
Le Buanec (1972)	Fresh	3.8	0.39	4.2
Rodriguez et al (1989)	Fresh	4.0	1.1	5.9
Degras (1993)	Fresh	3.1-4.1	0.38-0.51	4.0-4.8

Table 6. Percentage in plant at harvest (8 months) of D. rotundata.

	DM	N	P	K	Ca	Mg
Tubers	83.7	71.4	84	74.4	18.7	66.7
Stems	6.5	3.7	4	6.5	19.8	5.6
Leaves	9.8	24.9	16	25.6	81.3	33.4

From Irizarry, H. and E. Rivera (1985)

Table 7. Dry weight (Mg/ha/yr) of G. sepium prunings after the establishment year in several studies in the savanna zone of West and Central Africa.

Estimate	Prunings	Leaf	Stem
Kang and Van den Beldt (1990)	5.5	--	--
Otu and Agboola (1994)	8.5	--	--
Fagbola et al (1995)	4.6-8.4	1.6-2.4	3.0-6.1
Tossah et al (1995) Ultisol	3.2	1.7	1.5
Tossah et al (1995) Alfisol	8.0	4.6	3.4

Note: Fagbola et al. (1995) included all woody parts in the stem sample while Tossah et al. (1995) included twigs in the leaf sample.

Table 8. Above ground dry weight (Mg/ha) and N content (kg/ha) of M pruriens var. utilis in several studies in the savanna zone of West and Central Africa.

Estimate	Leaf + Vine	N content	Time
Hauser and Nolte (2002)	3.3-6.7	63-144	25
Chikoye and Ekeleme (2001)	1.8-3.6	--	16
Vanlauwe et al (2000)	6.1-6.9	115-145	18
Houngnandan et al (2000)	4.4-6.0	63-94	20
Carsky et al (1999)	3.4-6.2	85-154	16
Becker et al (1998)	1.0-12.7	20-160	20
Segda and Hien (1998)	8.5-9.0	193-211	20
Ibewiro et al (1998)	6.4	290	13
Muhr et al (1998)	4.2-6.0	--	36
Sanginga et al (1996)	7.7	325	12

Recommendations for development

- Generally, the application of more than approximately 40 kg N, 40 kg P_20_5 and 40 kg K_20 is rarely justified. This is because the largest effect of fertilizer occurs with the first increments in conditions responsive to fertilizer. Under conditions of poor response to fertilizer (for whatever the reason), small doses will result in less waste.
- Under conditions of low yield potential due to, for example, late planting, small mounds or ridges, small sett size, etc., high fertilizer recommendations are difficult to justify. The above recommendation can be considered as a maximum.
- Residual effects should be taken into effect. Fields that have received P fertilizer in the last 5 years do not normally need P fertilizer application.
- High value yams for pounded yam, such as Kpouna (Puna, Kponan) and Laboko, are those that most require high levels of OM. Cropping/fallow systems to provide OM to the soil should be acceptable to farmers who have a wholistic view of costs and benefits. Only high value yam may justify: 1) the high labor cost of transporting OM, 2) occupying the field for a year with a cover crop, or 3) the reduction of planting density and the increased labor involved in using the live staking agroforestry system.

Recommendations for research

- Residual effects of K fertilizer should be determined.
- Total nutrient uptake in the yam crop should be estimated in a limited number of trials.
- Yam systems that require OM and those that can benefit from small amounts of fertilizer need to be identified.

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Annexes

Annex 1. Fertilizer recommendations for yam in West Africa. Irving (1956) reported on a major project of fertilizer trials in southeastern Nigeria from 1947 to 1951. There was a marked response to N application and a lesser response to K, while a response to P was rare. The fertilizer recommendation for yam in eastern Nigeria in the 1950s was 50g of N-P_2O_5-K_2O 12-12-18 per hill (Coursey, 1967). Since then, there have been many recommendations for fertilizer for yam in Nigeria.

- 200 kg/ha of 10-10-20 in southwest Nigeria (Ojo 1969),
- 12-12-18 in southeast Nigeria (Mann 1963),
- 125-250 kg/ha of ammonium sulfate in Nigeria (Onwueme and Charles 1994),
- 72 kg of N as urea, 22 kg of P and 72 kg of K per hectare at Umudike in southeast Nigeria (Enwezor et al. 1988).

More recently in Nigeria, Obigbesan (1981), recommended:

- in the north : 25 kg ha"1 of ammonium sulfate,
- in the southeast: 400 to 600 kg ha1 of NPK (12-12-17) with a supplement of Mg,
- in the southwest on acid soils : 300 kg ha1 of NPK (12-12-17) + Mg;
- in the southwest on other soils: 50 kg ha1 of N and 60 kg ha1 of K^2O.

On Ultisols at Umudike in the degraded humid forest ecology with total N of 0.09% N, exchangeable K of 0.08 mg/100g and available P of 20-25 mg/kg, optimum yield of yam was obtained when fertilizer rates of 90 kg N, 0 kg P and 75 kg K/ha were applied. A recent review of chemical conditions favorable to yam production in Nigeria. (Ohiri 1995) recommended 81-90 kg N, 0-20 kg P and 0-62 kg/ha based on soil tests and calibration studies to maximize tuber yield with reference to compound fertilizer NKP 15.15.15, The application of 200 kg/ha was recommended in the southwest. In the Southeast zone, recommended 600 kg/ha. Under yam/cassava/maize intercrop, recommended the application of 800 kg/ha to be applied at 8 weeks after planting.

The technical bulletin published by INRAB (1995) in Benin calls for an unspecified amount of TSP and 100 kg/ha of KCl. The recommendation in Togo is 50 kg of P_2O_5 and 60 kg of K_2O but this is based on 2 years of observation at one site in the savanna zone. Trials conducted in Côte d'lvoire show that application of 14 g NPK/plant (10-18-18) and 7 g /plant of urea give yield increases of 9 to 121% (Dumont and Tokpa 1989).

Annex 2.

Fiche technique pour la fertilisation de l'igname en Côte d'lvoire (Technical bulletin for yam fertilization in Côte d'lvoire)

- L'igname est exigeante en azote et en potasse. Les besoins en phosphore sont modestes. Le calcium et le magnésium sont nécessaires pour obtenir des rendements élevés. L'expérimentation a montré qu'il est bénéfique de fractionner la fertilisation. Ceci est surtout vrai pour 1'azote.
- La fertilisation de l'igname ne peut être définie de façon simple. Elle doit être modulée en fonction des situations très diverses qui peuvent se présenter.
- Après une très longue jachère, la fertilisation peut ne pas être rentable. Quand 1'igname est introduite dans un système permanent d'agriculture, les quantités d'engrais à apporter dépendent de plusieurs facteurs dont le niveau d'intensification pratiqué et le type

d'igname utilisé.

Fiches techniques

Dioscorea cayenensis à deux récolte: la fertilisation
Derrière une vieille jachère, la fertilisation n'est pas nécessaire. Quand les conditions de fertilité sont moins bonnes ou encore dans les zones très sèches, on apportera la fumure suivante (par butte):
-après la levée (stade 8-10 feuilles), 20 g d'engrais coton (10.18.18) ou 20 g d'engrais ananas (8.4.20.4Mgo);
-40 à 50 jours après la levée (début de la tubérisation), 10 g d'urée et 10 g de chlorure de potasse. L'engrais doit être apporté en couronne, au niveau du tiers inférieur de la butte. La production de seconde récolte (semenceaux) peut-être sensiblement augmentée (+ 50%) en apportant, immédiatement après la première récolte, 50 g par butte d'un mélange comprenant 150 kg d'engrais coton (10.18.18) et 50 kg d'urée.

Dioscorea cayenensis à une récolte: la fertilisation.
Derrière une jachère la fertilisation n'est pas nécessaire.
Dans les auties cas, on apportera la fumure suivante (par plante):
-après la levée (stade 8-10 feuilles), 13 g d'engrais coton (10.18.18) ou 13 g d'engrais ananas (8.24.20.4Mgo);
-50 à 60 jours après la levée (début de la tubérisation), 6,5 g d'urée et 6,5 g de chlorure de potasse.
En culture mécanisée, on peut procéder de la façon différente:
-avant le billonnage, 100 kg/ha d'engrais coton ou d'engrais ananas et 50 kg/ha de chlorure de potasse;
-50 a 60 jours apres la levee, on apportera 6.5 g d'uree par plante.
Lorsque 1'engrais est apporte sur billon, il faut Ie disposer en couronne autour de la plante. Il faut eviter de mettre 1'uree en contact direct avec les tiges d'igname.

Dioscorea alata: fertilisation
Derrière une vieille jachere, la fertilisation n'est pas necessaire. Dans un système intensif d'agriculture, il faut d'abord veiller a ce que L'igname ne soil pas introduite sur un sol acide. Au cas echeant, 1'acidite doit etre corrigée par un amendement calcaire (500 g de dolomie a 1'hectare au labour). Toujours dans un système intensifd'agriculture, la fertilisation preconisee pour Ie *D. alata* est la suivante: au labour, 200 kg/ha d'engrais colon (10.18.18) et au 70 ejour de vegetation, on apportera 100 kg d'uree/ha et 100 kg de chlorure de potasse/ha.

L'apport de 1'engrais, en cours de vegetation, doit se faire plante par plante en évitant le contact entre 1'engrais et la plante. La quantité d'engrais à apporter à chaque plante doit e é tre calcul é e en fonction de la densit é de plantation.

Boilable cassava varieties: What is their role within the context of the global agricultural economy?

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Abstract

Cassava production and utilization in Cameroon have undergone a long evolution. The post-independence and pre-1990 eras were marked by activities that considered cassava to be a subsistence food crop. During this period, farmers relied on coffee and cocoa as the major cash crops. Cassava growers used mainly boil–and–eat varieties that could be sold in local markets.. The crop gradually became important as a cash crop when coffee and cocoa prices fell in the world market. In recent years, cassava has gained prominence in all parts of the country where the crop is now grown for cash. Varieties responding to this market demand have had to be developed and disseminated to growers. The issue of the types of varieties needed to give cassava its place in the world market needs to be revisited. Effective processing and high quality control of processed products have to be addressed adequately for cassava to insert itself in the global economy.

Key words: cassava, culinary properties, Agricultural economy

Introduction

Cassava is an important staple in Cameroon where it furnishes the most calories in the diet of more than half of the population. Cassava growers in Africa have received many improved varieties in the past, yet more than 60% of cassava fields are still planted with local varieties. Growers indicate that they keep these local varieties because they possess certain attributes that they hold in high esteem, such as "mealyness," dry matter content, short cooking times, and high productivity.

In Cameroon, after the Cameroon National Root Crops Improvement Program was created, several new varieties were developed and distributed to growers. Years later, surveys made to determine the levels of adoption showed that growers in several zones of the country had retained very few of these varieties. The reason given for the low adoption was the poor cooking quality of the newly released varieties. A new breeding program was thus started to provide varieties with improved cooking qualities for growers in those regions where the earlier varieties had been rejected. Surprisingly, it has been observed that the proportions planted to the formerly rejected varieties and to those recently developed for good 'cooking quality are about the same when hectarages are compared. This paper highlights issues relating to the evolution of the cassava industry in Cameroon within the context of the development of cassava varieties in the country.

Characteristics of pre-1990 cassava varieties in Cameroon. The Cameroon National Root Crops Improvement Program was organized in 1977 after a tri-partite agreement was signed between the Canadian International Development Research Centre the Belgian Agency for Cooperation in Development, and the Government of Cameroon, with the technical assistance of the International Institute of Tropical Agriculture, Ibadan, Nigeria.

In Cameroon, cassava is consumed boiled or processed. In the monomodal rainfall forest and the moist savanna zones where cassava is an introduced crop, the roots are mainly processed into *gari,* flour, and traditional pastes (*miondo* and *mintoumba*). In the bimodal rainfall forest region (home of cassava utilization in the country), on the other hand, a portion of the harvest is consumed directly as boiled roots, and the rest are processed into a paste (*bobolo*) and other products. The local markets are fed with both fresh roots and traditionally processed products. Because of the diversity of uses in the various parts of the country, growers' preferences for appropriate varieties have also differed with time.

After 7 years of cassava research, high yielding varieties, resistant to the major diseases and pests, were released and distributed to growers. Among these varieties were 8034, 8061, 8017, 820516, 1005, 1187, 1198, 224, 465, and 8117 (Table 1).

The varieties 8034, 8061 and 8017 were widely accepted in the monomodal rainfall forest zone (in the Southwest and Littoral administrative provinces of the country). Later, national surveys were conducted and growers were interviewed to determine the reasons for the high rate of adoption of these varieties in that area. Results showed that in that area cassava was all processed into flour (*kum-kum* and *water-fufu*), *gari*, and *miondo*. In contrast, in the bimodal rainfall area of Cameroon, growers adopted only one (1005) of the 14 improved varieties released, (Ngeve and Fouda 1987). Here, it was later discovered that consumers wanted boil-and-eat types, and so growers were willing to grow only multi purpose types, that is, those varieties which could be boiled and also could be processed. In the bimodal rainfall forest area, the traditional way of using cassava is that when roots are harvested, some are boiled for direct consumption and the surplus processed into *bobolo*, traditional fermented paste.

Characteristics of post-1990 cassava era in Cameroon. Baseline diagnosis of cassava growers' constraints after 1990 showed that the major field and consumer problems were: (a) lack of high yielding boilable varieties; (b) lack of varieties carrying adequate field resistance to the *cassava mosaic virus*, cassava root rot, and anthracnose diseases; and (c) lack of control measures for the African root and tuber scale.

After 1990, it was then realized that the cocoa and coffee boom was over, and much emphasis was now placed by growers on crops, such as cassava. Growers could educate their children with relative ease with proceeds from the sale of a substitute crop (cassava). Yet many consumers in some parts of the country still needed varieties which they could boil and eat and also could process into local food forms. There was thus a need to develop such multi purpose varieties. A new cassava development Program initiated to address these constraints yielded the varieties, Excel and Champion, with fresh yields of about 38 t/ha (Table 2). Although these varieties were high yielding and had high starch content, their adoption was limited because of low dissemination as a result of a lack of planting material for an ever-growing farming population.

The Food and Agriculture Organization (FAO) in its Technical Cooperation Program, offered to assist the Government of the Republic of Cameroon in the rapid multiplication and distribution of high yielding varieties adapted to the various regions of the country. This 2-year Program established primary, secondary, and tertiary multiplication plots all over the cassava growing regions, trained growers on rapid multiplication techniques and opened Farmer Field Schools in six zones to disseminate production technologies. In this scheme, some 20 million cuttings of improved and adapted varieties were distributed to growers in various parts of Cameroon.

Characteristics of the current cassava industry in Cameroon. It was soon realized that growers were not obtaining earnings from the local cassava industry commensurate with the efforts they were putting into it. Better proceeds could be obtained only from processing, since processed products were seen to have a longer shelf life and could be marketed over a longer period of time. Hence, those varieties developed earlier, which had been rejected at that time because they did not meet the boil-and-eat needs of the consumer population in some regions, were now reconsidered for cultivation; the same growers now turned to accepting the varieties they had earlier rejected. Interviews conducted with farmers to determine the reasons for this change in attitude showed that many growers are no longer small-scale farmers but big, modern producers, most of them *retired* ministers, Directors-General of states and private corporations, and bank managers. These modern producers have several characteristics in common: (a) many have travelled extensively out of the country and have seen broader opportunities for cassava; (b) they have been to and made contacts with foreign and international markets; (c) they are ready to invest in a crop which they know has tremendous potential in international trade; (d) they have the resources to afford the services of hired labor to expand cassava hectarages; (e) they can afford to fund processing units to pre-process roots on a large scale; (f) they can handle external marketing hurdles, and (g) they can afford to purchase or rent the needed land and equipment for large-scale farming. Such modern growers are now growing cassava mainly for cash. These characteristics have transformed cassava from subsistence to a cash crop.

Cassava has also become more popular because over the years, several processed products have entered the diets of many consumers in areas where their traditional staples have failed. This is the case with the *Bakweri* populations in the Southwest province of Cameroon who have replaced cocoyam *fufu* with cassava *fufu* because the prevalence of a fungal root rot has grossly reduced cocoyam production in the area. This means that those varieties which were initially high yielding and high in dry matter content are now considered acceptable for cultivation. Therefore, the earlier varieties, 8034, 8017, and 8061, are now grown to a large extent by growers even in areas where they had formerly been rejected. This has revolutionized cassava cultivation, as yields have continued to increase with the rapid adoption and use of these superior genotypes, considered appropriate as long as they are high yielding (in storage roots), and have high dry matter and high starch content.

The cassava revolution–the role of cassava in the global cassava economy. The agricultural system of today produces more food and food products to feed the ever-growing world population which stands now at 6 billion (Curtis 2001). Yet some 840 million people, most of them residing in developing countries, still remain underfed, making food insecurity and hunger a part of everyday life. If cassava is to participate effectively in the global economy, certain attributes will have to be met. Today's varieties must (a) produce high dry matter yields, (b) possess high starch content, and at the same time (c) resist major environmental and climatic hazards. The challenge today is to increase productivity, marketing opportunities, and profitability: introduce technologies in the sub sector that will drive down costs of production, harvesting, processing, and marketing; (ii) improve quantity, quality, and standards of products for diversified uses; (iii) make products competitive with other raw materials and enhance public and private sector partnerships. In each African country, cassava processing must also ensure high quality control standards to make locally processed products competitive with those produced externally.

For now, processed cassava food products from Cameroon are sold in regional markets in Gabon, Equatorial Guinea, Central African Republic, and Nigeria. Even in those parts of the country which produce enough cassava, weak distribution systems, isolated populations, and the long distances between producing areas and consumption centers cause a glut in local markets and food shortages in urban areas. Yet it is generally agreed that it is only with rising farm incomes that poverty can be reduced (Joekes and Weston 1994; Joekes et al 2000). Therefore, in order that the full potential of the cassava crop can be realized in Cameroon, industrial processing of roots into starch and flour has to be encouraged and improved. Also, the complex web of modern cassava producers, consumers, local, regional, and international markets, developed and developing countries, and domestic and international politics, must be properly understood to know how they are interacting to shape cassava agriculture in a global economy. If this complex network is understood and competitive production is ensured, rural incomes will increase. This will result in rural development which, in turn, will ease urban poverty by slowing down the migration of the youth from the countryside to the urban areas.

Cassava has many uses, most of them derived from starch and flour. It has often been said that "what starch can do, cassava starch does best." Its starch can be used (a) as fillers in tablets and other pharmaceutical products (b) as a syrup concentrate in soft drinks and canned foods; (c) as a binding agent in processed foods; (d) in bakery and confectionary (bread, biscuits, etc,); (e) as a thickener in soups and baby food, and (f) as a sweetener in the production of glucose, maltose, fructose, and monosodium glutamate (Knight 1969).

Some countries, such as Thailand and Brazil, have improved their economies through the sale of cassava products, most of which are exported to the European Union countries, the USA, China, and Japan, where the storage roots, packaged and shipped as dried chips and starch, are used in the manufacturing of cosmetic, pharmaceutical, and construction products. In these developed countries, high quality starch is used in the production of gum, and monosodium glutamate, in coating capsules, in the wet stages of paper manufacturing, and in soft drinks. Cassava is likely to play a similar role in Cameroon if the production, processing, and marketing are organized, and quality control is ensured and enhanced for competitiveness.

The quality of cassava processing needs to be enhanced with regard to the quality control of starch and flour, the two major commodities from African cassava in high demand. To ensure that locally made high quality starch and flour are utilized by local processing industries and for them to be acceptable to meet the exigencies of the international export market, productivity enhancement along the value-chain, and high quality control procedures have to be adopted and processors guided to ensure a regular flow of these products to the common market and in local bakery, cosmetic, pharmaceutical, paper, plywood, and other industries. An increase in this domain will naturally lead to a reduction in the dependence on foreign starch and flour for home industries and the need to spend foreign exchange to purchase these commodities. For instance, in the bread industry, it has been shown that compounding 30% of cassava flour with 70% wheat flour can produce bread which is just as good as whole wheat bread (Kim and De Reuter 1968a,b). High quality flour may even allow an increase in the proportion of cassava flour in the mixture, and reduce dependence on wheat flour for a commodity (such as bread) which is widely consumed now in Africa.

Conclusions

Cassava is now a commercial crop with production oriented towards a market economy. Value-addition and productivity enhancement along the value-chain must be emphasized. Harvested roots must be processed into chips, flour, and starch to prolong shelf life and increase value. Although the small-scale farmers are still in the minds of researchers, in order that the growers can effectively assure their families' livelihoods, health, and food security, they need to increase production hectarages to achieve economy of scale, through the use of superior varieties, agricultural inputs to maintain fertility and control pests, mechanized land preparation, machine-assisted harvesting, and processing into competitive products which can be sold for a large profit margin in

Table 1. Characteristics of main cassava varieties released prior to 1990 in various zones in Cameroon.

Zone	Variety	Root yield† (t/ha)	CMD‡ severity s core (1−5)	Cooking quality characteristic
Monomodal rainfall forest zone (Southwest and Littoral provinces)	8034	34.0	1.2	Non-boil
	8061	34.5	1.5	Non-boil
	8017	32.8	1.4	Non-boil
Bimodal rainfall forest zone (Centre, South and East provinces)	1005	36.0	1.8	Boil
	1187	32.5	1.5	Non-boil
Moist savanna (Adamaoua province)	224	35.0	1.4	Boil

†Means of three years (Source: adapted from CNRCIP 1984); ‡cassava mosaic virus disease on a score of 1 to 5 where 1 = no symptoms and 5=severe damage.

Table 2. Characteristics of main cassava varieties released in the bimodal rainfall forest zone of Cameroon after 1990

Yield			Pest and disease severity		
Variety	Fresh yield (t/ha)	Dry matter content (%)	CMD*	CRR+	ARTS‡
Excel	37.5	32.5	1.0	1.3	1.0
Champion	38.0	31.0	2.0	1.5	1.0
92/80297	39.0	29.6	2.3	2.5	2.4
92/8520	37.5	30.2	2.5	2.8	2.5
94/01569	35.0	30.1	2.8	3.0	2.0
94/081	35.0	29.3	2.5	2.8	3.1

*CMD (cassava mosaic disease) on a score of 1 to 5 where 1 =no symptoms and 5 = severe damage.; +CRR (cassava root rot) on a score of 1 to 5 where 1 = no symptoms and 5= severe damage; ‡ARTS (African root and tuber scale) on a score of 1 to 5 where 1 = no damage and 5 = severe damage.

developing and developed countries and over a longer period of time. Only then can cassava in Cameroon take its place in the global economy.

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Developing cassava cultivars based on farmers' needs and on the agro-ecological conditions of north-western Cameroon

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Abstract

Cassava is one of the most important staple food crops in Africa and has recently been gaining importance as a cash crop for smallholder farmers. The dynamics of the system requires new cultivars. The broad objectives of the present study were (a) to specify the need for new cassava varieties; (b) determine the level of G × E interaction in the area; (c) to suggest an effective way to select cultivars in the agro-ecologically diverse environment of the mid-altitudes of Central Africa. We proceeded by a farmers' evaluation of varieties grown on-station, by a formal on-farm variety trial, and by semi-structured interviews. We found that only a few cassava cultivars were available, given the agro-ecologically diverse nature of the area. Farmers preferred new cultivars with a high yield, to best exploit the opportunities related to the high, mainly urban, demand for cassava processed into *gari*. In addition, they preferred cultivars which do not require processing other than boiling, to break the labor peaks implicated in gari production. In the on-farm variety trial, G × E interaction is observed to be lower in the high-potential fields (storage root yields >8.9 Mg ha^{-1}) than in the low-potential fields (storage root yields <8.9 Mg ha^{-1}). The present distribution pattern of local cassava cultivars was found to be based on G × E interaction. We propose a decentralized participatory variety selection scheme to overcome the challenges of G × E interaction in variety selection. The commonly practiced exchange of planting material among farmers will encourage the fast and effective dissemination of new genetic material.

Key words*:* Decentralized participatory variety selection; cassava cropping system; farmers' variety management; genotype × environment interaction; Cameroon

Introduction

Cassava is, together with maize, common beans, cocoyam, yam, plantain and rice, among the most important staple food crops of the North-West Province (NWP) of Cameroon. Mainly produced for home consumption after its introduction to the NWP around 1920 (Ohadike 1981; Warnier 1984), cassava became one of the very important in the area in the mid-20th century. Today, cassava is also a cash earner. Its processed products are very popular with the urban population, because they are easier to prepare and can be kept longer than the other staple crops, *gari* is made from cassava storage roots, grated, fermented, and roasted in palm oil. The dry yellowish granules are ready for consumption after mixing with water. *Waterfufu* is made from cassava roots that are fermented, pounded and sieved. The white paste can be kept for up to 4 weeks. The trend to produce more cassava is furthermore promoted by the fact that this crop can be grown under a wide range of biophysical conditions. Cassava also grows on soils which are too depleted for the successful production of other staple crops, such as maize (Prudencio and Al Hassan 1994; Bakia et al 1999). In view of the changing role of cassava and the changing environment, new cassava varieties are required. This article wants to provide breeders with information on how farmers in an agro-ecologically diverse environment of the mid-altitudes use old and new varieties, and which varieties will be required in the future. It also determines the level of G × E interaction in the area; and suggests a decentralized participatory variety selection scheme (PVS) in the case of cassava in the NWP, aiming at making variety selection and dissemination as efficient as possible.

Cassava cropping system in the NWP. In the North-West Province, as everywhere in Cameroon, cassava is produced by small-scale farmers (Simeu Kamdem 1996). Our preliminary studies showed that cassava farming is limited by the availability of labour rather than land availability, since cassava can be grown on marginal soils. The area grown to cassava, planting time, care (weeding) given to the crop, and quantity processed into *gari* largely depend on labor availability, which is determined by the family structure, the health of the farmer, and the possibility of hiring labor. In the humid savannas of Cameroon (to which the NWP belongs), 80% of the farmers growing cassava for home consumption also plant it as a commercial crop (own observations). Unlike many other crops, it receives little or no external input in terms of fertilizer or plant protection chemicals. Cassava in the NWP is planted at 20,800 plants /ha, which is twice the recommended planting density (Okeleye et al 2001). Harvesting is done continuously, and in small quantities. Farmers harvest as much as they can process within a few days, and large quantities are harvested only when larger sums of cash are needed. Processing is done at home or in community infrastructures. *Gari* is a predominant income earner for farmers, but it also plays an important role in home consumption.

Demand for new cassava cultivars. Considering the growing demand for processed cassava products (especially *gari*) in the NWP, high yielding cultivars with high dry matter content are required. This need can be met either with a few cultivars with a stable performance across farmers' highly variable agro-ecological conditions, or by many different cultivars, each of them adapted to a specific agro-ecological pocket, (Prain et al 1991; Witcombe et al 1996; Ceccarelli et al 2000). Since farmers preferences for qualitative traits are quite uniform in our case (own observations), it would indeed be possible to opt for a few stable cultivars. However, to exploit as much as possible the potential of a batch of newly developed cultivars, a selection scheme should allow for the dissemination of many different cultivars. In addition to physio-ecological adaptation, cultivars to be grown in the NWP require to be resistant or tolerant to the *African cassava mosaic virus* (ACMV) and the cassava green mite (CGM; *Mononychellus tanajoa* (Bondar); Acari: Tetranychidae). Ideally, new cultivars should support the neotropical predatory mite *Typhlodromalus aripo* DeLeon, 1967 (Acari: Phytoseiidae), which today controls CGM in about 20 countries of sub-Saharan Africa. Establishment of *T. aripo* is facilitated by plants with hairy and year-round turgid apices (Hanna et al 2000; Hanna and Toko 2002; Zundel et al 2009). However, only about 3% of the cassava plants in farmers' fields in the mid-altitudes of the NWP presently have hairy apices, and repeated efforts to establish *T. aripo* in this area have failed so far (Zundel et al unpublished.); although *T. aripo* is established in the lower altitudes of the NWP (Zundel et al unpublished.).

Cassava variety development at present. Cassava breeding largely relies on selection of F_1 clones over several clonal generations. In Africa, material performing well in advanced multilocational yield trials of the International Institute of Tropical Agriculture (IITA) in Ibadan, Nigeria, is passed to national cassava programs in other countries and to other IITA research sites. In 2000, about 200 new cassava clones were introduced by IITA for field evaluation in three locations in Cameroon – Bibi Ngoum, Center Province; Nkoemvon, South Province; and Bertoua, East Province. All cassava clones developed by IITA and used in the trials reported in our study had been selected from the introduction in 2000 or earlier.

The Rural Training Centre Fonta (RTC Fonta), which is located about 20 km east of Bamenda, the Provincial capital of the NWP, has been involved in cassava improvement since 1994 (Bakia et al 1999). It had received new cultivars over several years through the IITA-coordinated Ecologically Sustainable Cassava Plant Protection (ESCaPP) Project. At the beginning, a series of several hundred local cultivars collected in Cameroon (hereafter referred to as ESCaPP cultivars) was obtained. A second batch of 10 clones from IITA – selected on the basis of their performance in Nigeria and their resistance to ACMV was obtained in 1999 and widely used in the context of the present study. RTC has since obtained over 100 additional clones after evaluation by IITA at the Mbalmayo station in Center Province.

Need and challenges for a new cassava variety selection scheme. The cultivars provided to RTC Fonta had been developed at altitudes below 1000 m asl. Owing to the fact that large parts of the cassava growing area of the NWP are located above 1000 m asl, the need is obvious for a further selection and dissemination step. It has been demonstrated repeatedly (Iglesias et al 1994; Tan and Mak 1995; Dixon and Nukenine 1997; 2000) that G × E interactions can be significant in cassava farming. Indeed, farmers of the NWP insist that they cannot select new cultivars on the basis of performance in on-station trials; they need to grow them in their own fields to assess them. This statement suggests G × E interactions in cultivar performance. If the assumption proves true, cultivar testing and selection should be organized in a decentralized way. This can be realized only if farmers are willing to bear the main part of experimentation.

Cassava has a low multiplication rate (about 10 plants out of one plant / year), which presents a specific challenge to cultivar selection and dissemination programs. Successful selection schemes require that selection, targeted promotion, multiplication, and distribution are well tuned.

Materials and methods

Farmers involved in the study. The study was conducted within the outreach of RTC Fonta. The farmers involved in the work presented here came from six villages in the Mezam Division, NWP. They were smallholder farmers of the Bafut ethnic group, who had grown cassava for at least three cropping cycles as a cash crop for the rural and urban markets. Twenty-nine out of the 32 participating farmers were women.

Farmers' evaluation of an on-station variety trial. On the station of RTC Fonta, a variety trial with 10 cultivars was planted in June 2002. The purpose was to assess yield performance and parameters relevant to the biological control of CEM in a mid-altitude environment (Table 1). Each cultivar was replicated four times and each replicate consisted of 12 ×12 plants with spacing of 1 m ×1 m. Planting was done on ridges, as practised by farmers in the region (C. Zundel, pers. obs.). The trial area (100 m × 70 m) was bordered by two ridges planted with the cultivar ESCaPP 23 (name given by RTC Fonta). This cultivar is known to be very susceptible to ACMV and was considered a good source of virus inoculum to assess the susceptibility of the tested cultivars to ACMV infection. As practised by local farmers, no external inputs were applied in the experiment. Three hand weedings were done during the trial period.

Farmers were invited on two occasions to evaluate the cultivars: when the crop was 12 months old (aboveground evaluation) and 24 months after planting, i.e, at the time of harvest (above-and belowground evaluation). For the first evaluation, farmers were invited in small groups of two to four. In total, 12 farmers participated in the evaluation on five consecutive days. All farmers and their cassava fields had been visited by the research team at least once before the evaluation (see below). After an introduction to the purpose and the history of the trial, the farmers were given time to stroll through the field. The subsequent semi-structured discussions covered the following topics: observations concerning the aboveground appearance of the 10 cultivars and respective implications for field management and yield expectations; and preferences for specific cultivars at the present growth stage. A ranking of the importance of the preference criteria was done. The cultivars appearing in the top-three preference ranks of at least one farmer were selected for the on-farm variety trial (see below *On-farm variety trial*). In the second evaluation at the time of harvest, a similar procedure was applied. In addition, four plants / cultivar were harvested and their storage roots were boiled and served to the participating farmers for a palatability assessment. At the end of the day, farmers were allowed to select planting material from the varieties discussed, and the various choices were registered.

On-farm variety trial. To determine the level of G × E interaction, we planted an on-farm variety trial covering a total of 11 fields in five villages. The villages were located within a radius of 10 km, and each of the fields was considered as one replicate. At each site, the same five cultivars were planted that had been selected by farmers at the occasion of an on-station variety evaluation at RTC Fonta (see above *Farmers' evaluation of an on-station variety trial*). These were TMS 92/0057, TMS 92/0427, TME 1, and two farmers' cultivars from Cameroon labelled ESCaPP 30 and ESCaPP 32. Farmers were asked to add one of their local cultivars as a check. The trials were planted in August 2003 on ridges across slopes, and the cultivars were arranged side-by-side, stretching vertically across the ridges. Each trial field was bordered by at least four rows of a local cultivar. The fields were visited together with the farmers at 3-month intervals. At this occasion, semi-structured interviews were conducted on the farmers' observations concerning crop development, yield expectations, and perspectives regarding an eventual integration of the new cultivars into their portfolio. The fields were harvested in April 2005, i.e, 20 months after planting.

First, yield data were analyzed using all fields. To test the hypothesis that the potential yield of cultivars was affected by planting in high-potential or low-potential fields, we stratified the fields into six were high-potential and five were low-potential. The background of this hypothesis is the observation that favorable environments are often homogeneous, while marginal environments are more heterogeneous. We used mean yield over all fields and all cultivars (8.9 Mg ha^{-1}) as a criterion for separation. The Farmers' cultivar was excluded from the analyses, since this cultivar was different at each field. Data on yield / area and on the proportion of surviving plants at harvest were analyzed with a mixed model ANOVA (NCSS, 2000), with cultivar as a fixed factor and field as a random factor. Differences between factor levels were tested with a post-hoc test (Bonferroni).

In another approach to assess G × E interaction, we examined the distribution of the five most common local cassava cultivars in six villages of the NWP (Bambui, Fonta, Akossia, Asanje, Nibe, and Mfoya), which are situated within a circumference of 10 km. The inhabitants interact through family relations, farming groups, processing mills, market days, church activities, etc, (Zundel, pers. obs.). It is thus assumed that the existence of any specific cultivar is known in all the villages and that the present cultivar distribution pattern is a response to specific adaptation. We applied Fisher's exact test to see if distribution of these cultivars is random or if it is village-specific.

Visits to farmers' fields with semi-structured interviews. All farmers participating in the study were visited at least once. On the occasion of this call, fields were visited together and semi structured interviews were conducted on the role and importance of cassava, on various cropping practices, variety preference and variety management, field allocation, and cropping constraints.

Results

Existing cultivar portfolio, farmers' way to deal with new cultivars, and potential dissemination channels. *Variety preference criteria.* The visits to farmers' fields with semi structured interviews, and the on-station variety evaluation confirmed that the farmers' most important criterion for cultivar selection was yield in particular farmers who planted cassava as cash crop. Other positive (but optional) traits were (in order of descending importance): option to consume the storage roots after boiling (this implies soft tissue, nice taste, and lack of bitterness); early maturity; and flexibility in the harvesting period. We found that a mediocre yield was a killer criterion for the selection of a cultivar, regardless of how preferable the other characteristics were (see examples of TMS 92/0326, TMS 92/0239, and TMS 92/0427 in Table 1). Bitterness was always a negative trait in farmers' evaluation of a cultivar, but curiously, bitterness could be accepted if the cultivar produced a high yield (e.g, ESCaPP 30 in Table 1). Moreover, although farmers did not like "curled leaves" (ACMV symptoms), they would still accept the cultivar if other features (e.g, stem thickness) indicated a high yield (e.g, ESCaPP 23 in Table 1), as perceived by farmers.

When evaluating plants of new cultivars before harvesting, the more experienced cassava farmers tended to prefer cultivars which resembled those they grew themselves. In contrast, the less experienced farmers were keen on trying cultivars which looked completely new. For example, they preferred short cultivars over tall ones, while experienced farmers favored tall cultivars.

Variety portfolio management. In the six villages of our study, we identified 16 cassava cultivars, five of which were widespread. We learned of four more cultivars which farmers had once tried to grow but abandoned for various (unknown) reasons. Eleven of the 16 cultivars were "sweet" and could be consumed boiled. The remaining five cultivars were either "bitter" (which correlates with a high cyanogenic potential) or did not soften (within a reasonable amount of time) if boiled, and therefore had to be processed into *gari* or *waterfufu*. Farmers typically grew three cultivars, with an area-wide range of one to six cultivars. In addition, 25% of the interviewed farmers grew one or two cultivars on a very small scale (a few plants only). This was the case with cultivars which were not among the most favored, but where the farmers had decided to maintain them "for other times". Sharing planting material with other farmers was mentioned as another strategy to maintain cultivars.

Despite thein strong preference for high yielding cultivars, all farmers indicated that, at all times, they wanted a cultivar for home consumption, i.e, a cultivar that could be easily boiled and consumed (see also Ngeve et al. in press). Farmers with four and five cultivars indicated that they would replace a low yielder with a new cultivar if the latter was perceived to be of high quality. Farmers with two cultivars wanted to add one or two of the new cultivars to their portfolio. Based on these observations, four to five cassava cultivars appeared to be the optimum size of a cultivar portfolio of a farmer growing sole cassava. This is in accordance with the opinion of an experienced farmer who indicated that three or four cultivars were enough, if they produced well. However, a minority said that having many cultivars was an advantage as a farmer prepared for risks. They found 7 to 20 cultivars to be ideal.

Pure stands vs cultivar mixtures. We found that cassava cultivars were planted either in pure stands or in mixtures. We wanted to know if planting in mixtures was a deliberate choice and why. We found that farmers with large areas (>2500 m^2) under cassava usually planted in pure stands. If cultivars were deliberately planted in mixtures, it was either to avoid the risk of a complete crop failure – especially on marginal soils or on sites with unknown characteristics – or to achieve a specific blend of roots for *gari* production. Farmers indicated, however, that they were often challenged in finding cultivars that complement one another well in mixtures and do not compete with each other in a negative way. Unintended mixtures occurred if farmers did not have enough planting material of one cultivar to plant the whole field, or if the planting material was removed so long ago such that the cultivar name was no longer available. If cultivars were grown in mixtures, farmers usually recognized them in their fields and harvested them plant-wise, depending on their respective maturity and intended use. However, appropriate management and timely harvesting of plants and fields with unintended mixtures were said to be very difficult.

Management of planting material. Scarcity of planting material at the time of planting was said to be a major constraint in cassava farming. Although planting material is available in large quantities at the time of harvest, it may be lacking at the time when farmers want to plant a new cassava field. Constraints for planting a cassava field immediately after the harvest of another field were said to be: 1) land availability, 2) coincidence with peak labor needs for other crops, 3) health or other personal problems rendering the farmer unavailable for planting, or 4) the beginning of the dry season. The usual practice was that farmers collected stems as planting material from the harvested field and kept them in a cool and shady place. Alternatively, they left the stems in the field and selected the planting material from there when the time for planting had come. Once the roots are harvested, the stems gradually loose their vigor as planting material and it is not advisable to keep planting material for longer than 1 - 2 months, depending on variety and condition. Farmers were aware of that and attempted to plant the material as fresh when it was possible. Consequently, if farmers wanted to plant a new cassava field, they asked neighbors, relatives, or farming group members if they could provide planting material, particularly if mature plants of the other person's field looked vigorous. Large distances between fields were another reason why planting materials were traded: if farmers had harvested fields on one hilltop and had land for a new cassava crop available on another hilltop, they preferred to ask the neighbors of the new fields if they could provide cuttings than to carry their own stems from one hill to the next. In return, they gave away their own planting material to other farmers. Smaller quantities of planting material were selected before harvest by removing single stems from plants with two or more stems. This method had the advantage that the stems and leaves were fresh and farmers could do a selection for plants free from ACMV. If planting material is selected when mature cassava is harvested, the leaves are too senescent for ACMV symptoms to be reliably detected and identified. However, when selecting planting material, farmers actually gave more attention to strong and vigorous stems from plants with a high yield than to healthy leaves.

How farmers deal with new cultivars. The two main triggers for farmers to try new cultivars were either the lack of known planting material, which forced them into using planting material from a different source, or the high yield reputation of a cultivar. Planting material of new cultivars usually came from friends from nearby villages, from relatives, or from contractors with whom the farmers worked. Generally, farmers did not have much information about new cultivars when they decided to try them; the reputation of a cultivar to yield well was often sufficient as a basis for a decision. Some farmers considered the agro-ecological conditions of the origin of the new cultivar and compared them with their own environment before taking the decision to try. In most cases, farmers grew as much planting material of the new cultivar as they could get, ranging from a few plants to a whole field.

Potential dissemination channels for new cultivars. As described above, farmers often had to rely on planting material from other people, because they lacked their own material at the time or in the place they wanted to plant. Exchanging cuttings as gifts or requesting cuttings from somebody who had a "nice cassava" crop was also common. This free exchange of planting material among farmers could be an important basis for a low-cost and efficient dissemination of new cultivars.

Genotype × environment interaction. The on-farm variety trial in three villages on 11 fields, with five new cultivars plus one cultivar added by the farmers, showed no significant cultivar effect on yield (mean: 8.9 Mg ha^{-1}; $F_{4, 54}$=1.75, *P*=0.159) (Fig. 1). When grouped into high-potential fields (mean: 12.3 Mg ha^{-1}; n=6) and low-potential fields (mean: 4.9 Mg ha^{-1}; n=5), we found a cultivar effect in the high-potential fields ($F_{4, 29}$=2.92, *P*=0.047), but the difference could not be attributed to a specific cultivar with the post-hoc test. No significant cultivar effect was found on the low-potential fields ($F_{4, 24}$=1.48, *P*=0.256).

The percentage of plants surviving until harvest over all fields was 86%, but there were significant differences between cultivars ($F_{4, 54}$=6.49, $P<0.001$): ESCaPP 30, ESCaPP 32, and TMS 92/0427 had a higher plant survival rate than TME 1. While the cultivar effect on plant survival was not evident in the high-potential fields (mean: 87%; $F_{4, 29}$=2.65, *P*=0.063), cultivars did have an effect on plant survival in the low potential fields (mean: 84 %; $F_{4, 24}$=3.73, *P*=0.025), with ESCaPP 30 had a higher plant survival rate than TME 1.

Cassava yield varied considerably among fields (high-potential sites: $F_{5, 29}$=6.62, $P<0.001$; low-potential sites: $F_{4, 24}$=7.05, *P*=0.002) at high-potential as well as low-potential sites; however, plant survival was statistically similar across fields (high-potential sites: $F_{5, 29}$=1.03, *P*=0.426; low-potential sites: $F_{4, 24}$=1.22, *P*=0.340).

The second study to quantify the site effect on cultivar performance was based on the geographical pattern of local cultivar use. Table 2 presents the distribution of the five most common cultivars in six villages. Only one cultivar (Local Pawpaw Leaf) was grown in all six villages. One cultivar (Fonta Cassava) was grown in five villages, one (Nkong) in four villages, one (Mambo) in three villages, and one (Nsongwa) in two villages. Fishers' exact test ($P<0.001$) showed that there was an association between villages and cultivars.

Discussion

Need for new cultivars: what is required? The need for new cultivars was assessed directly in interviews and indirectly during field visits. Considering the diversity of topography, vegetation, and crop uses in the area, We found that the number of cultivars presently grown in the area was small. Indeed, almost all farmers wished to have more cultivars or wanted to replace some of their own cultivars with higher yielding cultivars if these were available for them. This points to an insufficient availability of adapted cultivars in the study area. Hillocks (2002) reports similar findings for other countries in the cassava belt of Africa. Despite increasing demand for *gari*, farmers desired to have high yielding cultivars that could also be boiled and eaten without any further processing to satisfy their household need. Another reason may be that the labor for *gari* production within the family is sometimes scarce or difficult to plan. Growing high yielding cassava that can be sold also for fresh consumption gives farmers more flexibility in organizing their manpower. Because of the cultivar effect on plant survival found in the on-farm variety trial, emphasis should be given to cultivars that provide sufficient hardy planting material, and those that have a vigorous young stage, under both dry and wet conditions.

The study underscores the presence of strong demand for multipurpose cultivars with a high yield potential under the given agro-ecological conditions of the NWP. Since these conditions are diverse, farmers don't strive for one excelling cassava cultivar, but instead try to grow as many cultivars as possible, and seek the best growing conditions for each (Ch. Zundel, manuscript in preparation). Labor peaks and the availability of planting material are two major limitations of the present cassava cropping system in the area. Thus, new high yielding cultivars have to have a flexible harvesting time, to break the labor peak during harvesting and processing, and they must provide sufficient and long-lasting planting material. Similar constraints are reported by Hillocks (2002), Ceballos et al (2004) and Manu-Aduening et al (2006).

G × E interaction – Need for a decentralised variety selection scheme. The idea that a cassava variety selection scheme in the NWP will have to cope with considerable G × E interaction led us to test this hypothesis in an on-farm variety trial and in a study on the present spatial distribution of cultivars. Our assumption is supported by the fact that cultivar effects on yield were more visible on high-potential fields than on low-potential fields, where variation overrode any difference between cultivars. This is an indication that the divergence between marginal environments is larger than that between favorable environments. Thus, the lower the yield potential of an area, the more difficult it becomes to propose the "right" cultivar. The suspected G ×E interaction is further supported by the present distribution of local cultivars in the area: the planting of many local cultivars was restricted to a few villages, although the exchange of planting material was common among farmers, within and across villages. The interviews showed that farmers have a clear idea of G × E interactions. Farmers were able to tell on which soil and in which village a specific local cultivar performs well and where it did not. If farmers considered trying a new cultivar, they took into account the environment where the cultivar was presently grown and compared it with their own environmental conditions.

It becomes evident that conclusions on cultivar performance are valid only for the agro-ecological pocket where they were tested. Extrapolations to other agro-ecological pockets are not possible. Thus, every village, if not every farmer, must have the oppotunity to test the new genetic material. Strong G ×E interactions on a small spatial scale, and thus the need for decentralized selection schemes, were also observed in other cases. Kornegay et al. (1996) found that in Colombian bean growing, the differences between farmers' fields are as large as differences between researchers' and farmers' fields. Decentralized selection is also advocated by Sperling et al (1993) for bean selection in Rwanda, by Joshi and Witcombe 1996 and Sthapit et al 1996 for rice breeding in Nepal, and by Ceccarelli et al 2000 for barley selection in Syria.

Useful decentralized selection for cassava in the NWP of Cameroon means 1–3 trial sites / village. If there are cultivars that perform well in many sites, they may be directly promoted in new areas, since they seem to be stable over a wide range of conditions. But there is no harm if no such stable cultivars exist, and if each village has another set of best cultivars, since there is no need or pressure to narrow promotion to a few of the tested cultivars. The only pressure would be existing seed laws which make the release of many varieties expensive.

By concept, decentralized selection does not automatically mean participatory selection. In practice, however, farmers' participation is needed to make a decentralized selection affordable (Ceccarelli et al 2000). It has to be kept in mind that handing over selection from an institution to farmers does not mean an elimination of costs but a different distribution of costs among the stakeholders (Morris and Bellon 2004, Hoffmann et al. 2007). Zundel et al (manuscript in preparation) found farmers to be the best to plan, manage, and evaluate decentralized variety trials.

Outline for a participatory variety selection scheme in the NWP of Cameroon. A decentralized participatory selection scheme needs to rely on institutions (NGOs) operating at the local level and playing the role of an effective interface between breeders and farmers. The responsibilities of such variety hubs in the NWP of Cameroon are outlined in the following.

As a basis for farmers to select the cultivars they want to test in their village, the cultivars should be grown by the variety hub on suitable land ("on-station"). If done in a replicated trial, the multiplication of planting material and feedback to the breeders on the performance of these cultivars can go hand-in-hand. Planting material of new cultivars should be provided to interested village groups continuously over a certain time period.

The schedule for farmers' evaluation on the hub's station can be derived from the periods when farmers usually observe their cassava crop very closely, i.e., 3 months after planting (emergence and young development); 12 months after planting (after the dry season; canopy fully developed; probable diseases clearly expressed); 18 months after planting (*ex-ante* yield assessment and estimation of harvesting time); and at harvest (yield potential, processing qualities). To keep the system running smoothly, the variety hub needs to allocate resources that can provide about 50 cuttings / cultivar and / experimental on-farm site.

The breeder and the variety hubs need to collaborate in a way which allows the supply of new cassava cultivars to the target area at regular intervals. Cassava clones should be shipped to the variety hubs in the NWP as soon as they pass the advanced yield trials and are introduced to Cameroon. Since selection is usually done at Mbalmayo (Central Province) in the low-altitudes, many cultivars which could have been highly performing in the mid-altitudes might otherwise be dropped. Sperling et al 1993 emphasized an early involvement of farmers to prevent a loss of genetic material which could potentially be of interest to the end user areas. In this case, many more varieties got adopted because farmers were involved earlier in the selection process. A pre-requisite for the functioning of the proposed scheme is the regular arrival of

Table 1. Cultivars included in the on-station variety trial at RTC Fonta.

Cultivar	Origin	Name given by farmers	Yield (Mg ha-1)	Cooking/processing quality (assessed by farmers)	Appearance (assessed by farmers)	ACMV resistance	CGM resistance	No. of farmers selecting the cultivar for their own trial*
ESCaPP 30	Cameroonian cultivar	Bitter Purple	17.4 ± 0.29	Very bitter; very white; for *gari*	Tall; attractive leaf color	Slightly susceptible	Moderate	12
TMS 92/0057	Improved	Small Long Leaves	16.8 ± 0.18	Nice taste; cooks well	Tal	Resistant	Susceptible	14
ESCaPP 32	Cameroonian cultivar	Agric Pawpaw Leaf	13.9 ± 0.11	Slightly bitter; for *gari* or waterfufu	Tall	Susceptible	Resistant	15
TMS 92/0427	Improved	Short Short Stem	13.5 ± 0.49	Nice taste; cooks well	Short	Resistant	Moderate	5
Fonta Cassava	Local	Fonta Cassava	9.8 ± 0.06	Doesn't cook; for *gari* or waterfufu	Tall	Susceptible	Susceptible	2
TMS 92/0326	Improved	Njamahnjamah Leaf	9.3 ± 0.03	Nice taste; cooks well	Short, branching	Slightly susceptible	Susceptible	0
TME 1	Nigerian cultivar	Plum Leaf	8.7 ± 0.25	Nice taste; cooks well	Tall	Slightly susceptible		Tolerant13
TMS 91/0239	Improved	Small no be Sick	8.0 ± 0.14	Nice taste; cooks well	Short	Resistant	Resistant	4
TMS 92/0235	Improved	Trouble Maker	7.8 ± 0.09	Nice taste; fibrous; for *gari* or waterfufu	Cross-branching	Resistant	Tolerant	0
TMS 30572	Improved	Folded Leaves	6.6 ± 0.16	Poor taste; for *gari*	Short	Resistant	Moderate	0

ESCaPP=Ecologically Sustainable Cassava Plant Protection Project; ACMV=African Cassava Mosaic Virus; CGM=Cassava Green Mite; * maximum of 18 farmers.

new genetic material. Good contacts and smooth collaboration between the breeder and the variety hubs are therefore crucial. More important than a high number of new cultivars is the regular provision of about the same number of new cultivars to the hubs, not to challenge the capacities of the station and the farmers, but to allow for the constant use of the capacities built up. This implies a more systematic way to work with farmers. A 2 -stage approach for cultivar exposure to farmers (similar to Sperling et al. 1993) could help: one or two lead farmers / village farming group are invited to evaluate the material at the variety hub and to take interesting material home for testing. This allows a hub to cover a wide area with planting material. Fifty cuttings / cultivar and / village field are sufficient. Moreover, the village test fields are closer to the farmers, in terms both of agro-ecological conditions and of distance. Farmers then select cultivars from the test fields in their own village and try them on their own land. In our case, Rural Training Center trainees with some experience in cassava farming are ideal to bring home cultivars from "their hub" at the end of their course, and to establish a test field in their village.

Based on the results of our field visits and interviews, the hubs should focus on providing nuclei of material to many villages, rather than multiplying and disseminating the new cultivars to all farmers. Once these nuclei are established in the villages, the new cultivars will naturally be disseminated through neighborhoods, farmers' groups, and relatives.

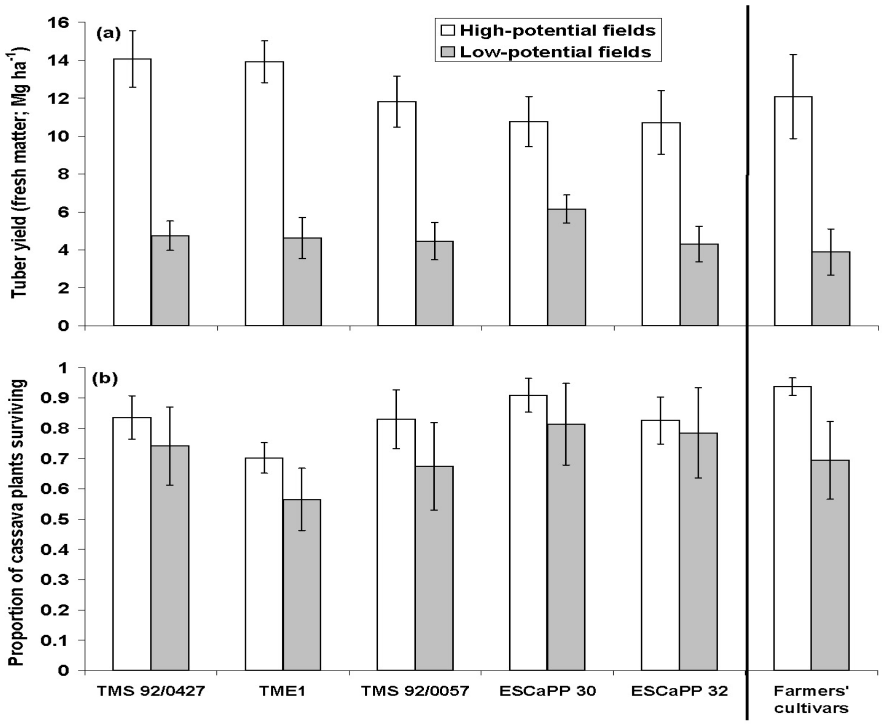

Figure 1. Yield (a) and proportions (b) of surviving plants of five different cultivars and the farmers' own cultivars on high-potential fields (n=6) and on low-potential fields (n=5). Data points are means. Vertical bars are standard errors of the means.

Table 2. Number of visited farmers / village and number of farmers who grow a specific cultivar.

Village	Mfoya	Nibe	Asanje	Akossia	Bambui	Ndoka
Number of visited farmers	11	2	2	3	3	7
Cultivar Fonta Cassava	10	2	2	0	1	1
Cultivar Local Pawpaw Leaf	10	2	2	3	2	3
Cultivar Nkong	10	2	2	3	0	0
Cultivar Nsongwa	0	0	0	0	3	7
Cultivar Mambo	0	0	2	0	1	6

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Screening plant materials for resistance to the yam nematode (*Scutellonema bradys*)

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Abstract

Experiments were carried out in the greenhouse and field of the Department of Crop Protection and Environmental Biology, University of Ibadan and the International Institute of Tropical Agriculture (IITA) to screen crops for resistance/susceptibility to the yam nematode *Scutellonema bradys*. The severity of susceptibility was closely associated with the number of nematodes that were recovered from the soil and roots of plants. Field and greenhouse evaluation of the reactions of 10 yam cultivars TDr 87/0072, TRr 93 – 31, TDr 131 (*Dioscorea rotundata*), TDa 92-2, TDa 85/00257, DAN 087 (*D. alata*), TDe 3041, TDe3037, TDe2786 (*D. esculenta*), Igangan (*D. cayenensis*) and seven other crops (*Xanthosoma sagittifolium, Ipomoea batatas, Zea mays, Cajanus cajan, Vigna subterranea, zingiber officicinale* and *Mucuna pruriens*) to *S. bradys* showed significant (*P*<0.05) variation in dry rot incidence. TDa 92-2, *Zea mays, Zingiber officinale, Xanthosoma sagittifolium* and *ipomoea batatas* proved to be non-host to *S. bradys* as the nematodes were unable to survive in the roots and cause damage. Variation in yield parameters (fresh weight of tubers, number of tubers per stand per plot and percentage dry matter) was significant at *P*<0.05. Results indicate allelopathy by the non-host crops. The gradual decline of nematode populations in plots planted with the resistant (non-host) plants confirms the ability of the plants to exude toxins and thereby survive the nematode attack.

Key words*:* Resistance*, Scutellonema bradys***,** susceptibility

Introduction

Scutellonema bradys is found in the peridermal and subperidermal layers, rarely penetrating deeper than 1 to 2 mm during the growth of the tuber. During storage, penetration can be greater in parts of the tuber (Adesiyan 1977). Initially small yellowish lesions develop, which are revealed if the yam skin is removed; these turn dark brown or black and, as the infection spreads, the lesions coalesce to form a continuous dark, dry-rot layer which can girdle the whole tuber. External symptoms of damage are slight, varying from deep cracks in the tuber skin, malformation of the tubers, and, in extreme cases the flaking off of parts of the epidermal layers exposing the dark-brown, dry rot tissue underneath, giving a mottled appearance to the tubers. *Scutellonema bradys* invades developing tubers by way of the tuber growing-point, alongside emerging roots and shoots, and also through cracks or damaged areas in the suberized epidermis (Bridge 1972). Infested seed tubers or tuber pieces are probably the main source of inoculum in the field. No true survival stage (Cyst formation, etc.) is known with *S.bradys* but populations are maintained in the absence of yam probably on other host plants. The objective was to identify yam cultivars and other crops that are resistant to *S. bradys* on the field through field and greenhouse screening.

Materials and methods

The crops assessed in the screening for resistance (greenhouse and field experiments) are listed in Table 1. Infested yam tubers of *D. rotundata and D. cayenensis* served as sources of inoculum. These were obtained from the International Institute of Tropical Agriculture (IITA), Ibadan and Ojoo market, Ibadan. Extraction of *bradys* from the infested tubers was by the use of the modified Baermann funnel extraction method (Whitehead & Hemmings 1965) the material was supported on a plastic sieve of about 6 to 8 cm diameter and 2 cm deep. Paper tissues were then placed on the sieves and the chopped yam peels or finely crumbled soil samples put in them. The sieves were placed in water in extraction trays. Overnight, the sieves were gently removed and the contents of the dishes examined for nematodes. The dishes can be reimmersed in fresh water for further extraction. This is necessary only when extracting from tubers.

Plants in field experiments were artificially infested using weighed quantities of infected yam peels for which the nematode content had been estimated. Plants in pot experiments were inoculated with nematodes extracted from yam peels. A greenhouse experiment was conducted using sterilized soil in 10-L plastic pots arranged in a completely randomized design and maintained at 25-28°C. Treatments were randomly assigned to pots with five replications. Sandy loam soil collected behind the Department of Crop Protection and Environmental Biology, University of Ibadan, was steam-sterilized in an autoclave for one hour, allowed to cool before being transfered into the pots. Test plant seeds were planted in the pots and were watered as necessary. Grain crops were planted two seeds per plant-stand per pot and one seed tuber per plant-stand per pot. Seedlings were thinned to one per pot 14 days after planting and inoculated with *S. bradys* at 28 days after planting (DAP). By way of inoculation, approximately 10,000 nematodes (Pi) were pipetted in 10-m1 aqueous suspensions into depressions in the soil around the roots of the seedlings. Pots were kept free of weeds. There was also the un-inoculated control. Plants were harvested 140 DAP. Matured tubers and roots upon a visual, qualitative inspection were rated for severity of disease symptoms on a 0-10 scale: 0= clean tuber; 2 = small yellowish lesions; 4 = dark brown lesions; 6 = continuous dark dry rot layer; *8* = deep cracks in the tuber skin; 10 = malformation of tuber and flaking off of parts of the epidermal layers. Mature tubers and roots were peeled and the disease severity of the tubers and roots was determined. Infested tubers and roots were characterized by dry rot tissue underneath. Nematodes were extracted from 100-cm^3 soil subsamples and 100g fresh root and tuber peels by a modified Baermann funnel extraction method (Whitehead & Hemmings 1965).

The field trial was carried out in the Teaching and Research Farm of the Faculty of Agriculture, University of Ibadan. The trial was complementary to the greenhouse experiment and involved screening the same cultivars of selected crops for reaction to yam nematode attack. The total size of the experimental area was 59 m x 19 m (plot size = 9 m^2). Yam spacing was 1 m × I m. The plot was cleared and ridges and mounds were made ready for planting. Two seeds per plant-stand (grain crops) and one seed tuber per stand (roots and tubers) were planted. Soil samples were taken to determine initial population densities (Pi) in the field, but no parasitic forms were found in the samples and non parasitic-nematodes were at relatively low population levels. Approximately 10000 *bradys* adults and juveniles were introduced per stand through known weights of infected yam peels added to the soil close to the base of the roots of each plant. The experiment was laid out in a randomized complete block design with five replications. Plants were harvested at 185 days DAP. At maturity, visible symptoms of nematode damage were observed following the method earlier described in the greenhouse study. Yield parameters − fresh weight and number of storage organ (tuber, root or corm) per stand and per plot, were also recorded. Nematode counts were recorded as numbers per 100-cm^3 soil and numbers per 100 g of fresh root weight or per 100 g of tuber peel following extraction using the Baermann extraction method already described.

At harvest (32 weeks after inoculation), mature tubers, corms, and roots were indexed for disease severity, and grouped into six classes as already described. Within the plots roots and tubers were counted and their fresh weights determined. Data obtained from greenhouse and field screening of plants for resistance to *S.bradys* were subjected to correlation analysis, analysis of variance and the means were separated by Least Significant Difference (LSD) and Duncan's Multiple Range Test (DMRT).

Results and Discussion

Resistance, as measured by absence or presence of *S. bradys,* is present in varieties of a number of plant species. This study showed that there was significant variation in the 17 crops screened for resistance to *S. bradys.* This was expressed in visible symptoms of infection, survival of nematodes on crops and the extent of damage caused by the nematodes on the various crops. The level of resistance of the crops ranged from very resistant to very susceptible. The crops were grouped into two classes (Table 2) based on their reaction to S. *bradys.* On the symptoms of infection, there was either an absence or presence of necrosis on the tubers and roots, when examined. Very few nematodes (or none as in some cases,) were recorded from the roots and surrounding soil of the non-hosts indicating resistance to *S. bradys*. Significant differences ($P \leq 0.05$) in level of susceptibility were observed among the susceptible crops. TDr 87/00072, TDr 93-31, TDr 131, TDa 85/00257, DAN 087, Igangan, TDe 3041, TDe 2786, and TDe 3037 had high nematode populations at harvest with mean values of 26510, 18108, 22506, 7600, 14460, 24405, 3022, 2461 and 4976 per 100 g peel respectively. The lowest population of nematodes was recorded in *Mucuna pruriens, Vigna subterranean,* and *Cajanus cajan* with mean values of 3366, 2071 and 2512 (Table 3). Soil nematode populations also showed a significant ($P \leq 0.05$) variation at harvest (Table 4). Some crops also recorded very low nematode populations at harvest. There was significant correlation between soil nematode population and the number of nematodes extracted from infected tubers and roots (r = 0.77), and between tuber weight and number of nematodes extracted from infected tubers and roots (r = 0.33). The correlation between tuber weight and soil nematode was not significant (r = 0.117). There was a significant reduction in fresh tuber weight in the infected cultivars.

There was variation in the visible symptoms of infection (necrotic lesion) amongst the crops, with those that were very susceptible (especially the tubers) recording the most pronounced lesions. This was expressed in the nematode population count as shown in Table 5. There were also resistant crops with no symptoms of infection or nematodes recovered from them. These include *Zea mays, Zingiber officinale, Xanthosoma sagittifolium* and *Ipomoea batatas*. TDa 92-2, however, showed a high level of resistance but recorded a susbstantial nematode population in the surrounding soil (Table 4 above). Significant differences ($P \leq 0.05$) in soil nematode population were observed among the crops. The two most susceptible hosts were the *D. cayenensis* and *D. rotundata* cultivars with 2508 and 2500 adult *S. bradys* per 100 g peel at harvest and 21.6 and 14.6% weight reduction. The highest soil nematode population was also recorded for *D. cayenensis* (20400), followed by *D. rotundata* (18422) and *Mucuna pruriens* (18377) while the lowest recorded soil population was recorded for cocoyam, ginger, and maize (10) (Table 4 above and Table 5). Soil nematode population and numbers of the nematode extracted from tubers and roots were significantly correlated (0.58) at 5% level of probability. However there was a negative correlation for soil nematode and tuber weight (r = −0.08 1). The correlation for tuber weight and number of nematodes extracted from the tuber was not significant (r = 0.079). There was a variation in fresh tuber weight as a significant weight loss was observed in infested tubers compared with the healthy tubers.

Crop cultivars resistant to nematodes can be the most useful and cheapest means of nematode control for farmers. In screening for resistance in these studies, emphasis was placed on susceptibility and resistance as expressed by the ability of *S. bradys* to survive and multiply on roots and tubers. The results from the greenhouse and field screening showed that the survival of the nematodes was limited in the roots of TDa *92-2, Zea mays, Zingiher officinale, Xanthosoma sagittifolium* and *Ipomoea batatas* and subsequently multiplication, whereas, the presence of nematodes in the soil and dry rots observed in the tubers, and roots of others, confirms their susceptibility to S. *bradys* attack. The severity of susceptibility was closely associated with the number of nematodes that were recovered from the soil and roots of plants. *Cajanus cajan* and *Vigna subterrenea* reduced populations at least as well as did *Mucuna pruriens.* TDr 87/00072, TDr 93-31, TDr 131, TDa 85/00257, DAN 087, TDe 3041, TDe 3037, TDe 2786, and Igangan are poor hosts for S. *bradys* and TDa 92-2, *Zea mays, Zingiber officinale, Xanthosoma sagittifolium,* and *Ipomoea batatas* are non-hosts. The capacities of these.crops for supporting yam nematode penetration and development can be evaluated. *Xanthosoma sagittifolium* is a non-host and is immune to penetration by the yam nematode.

At harvest, the nematode population density was zero, indicating that the yam nematode could not maintain itself under *Xanthosoma.* The general trend of reduced nematode numbers in the field combined with our greenhouse results showed that the other crop species are more tolerant to *S. bradys* than the yam cultivars. Our results indicate allelopathy by the non-host crops. The gradual decline of nematode populations in resistant (non-host) plants plots confirms the ability of the plants to exude toxins and thereby survive the nematode attack. *Zea mays* and *Zingiber officinale* are extremely poor hosts for the yam nematode, allowing only a few to penetrate and develop. The rapid nematode decline under these plants with those observed in other non-host plants supports the hypothesis of nematode population reduction by allelopathy, possibly by toxic thiophenes (Gommers and Baker 1988). The results of studies by Onalo et al (1998) showed that intercropping yam with ginger, cocoyam, and maize appreciated yield significantly.

In general, a plant resistant to nematodes resists attack or exhibits little damage and reduces nematode populations. Agronomically, a resistant variety may compare favorably with other available means of control in terms of its yield on infested land and its effects on nematode populations. The range of effectiveness of the resistance against different populations of the nematode must permit use of the resistant variety throughout the area of its agronomic adaptations.

In a similar experiment on comparative studies of resistance to yam nematodes, Mohandas et al (1996) and Bridge (1996) observed considerable differences in the root and tuber crops screened. Mohandas grouped sweetpotato as highly resistant and cocoyam as immune to the root-knot nematode. Out of the 55 farm sites on 29 crops surveyed for 17 plant-parasitic nematodes, Bridge reported that *S. bradys* was not found on cocoyam, ginger, or maize. Resistance of yam cultivar TDa 92-2 to *S. bradys* has not been reported before this study. However, there is no firm evidence of resistance to *S. bradys* in yam, and accessions of all the food yam species *(D. rotundata, D. alata, D. cayanensis* and *D. esculenta)* have been reported to be susceptible to damage. In the report by Caveness (1979) where three species of yam were greenhouse tested for resistance to *S. bradys, D. dumetorum* was highly resistant, but *D. praehensilis* and *D. rotundata* were highly susceptible. He found 21 lines of cocoyam, 55 of sweetpotato and 10 of *mucuna* resistant to the root-knot nematode out of the 21, 414 and 287 lines tested respectively (reported by Nematology Subprogram of IITA, 1982). A wide range of other crops and some weeds have been shown to support low populations of S. *bradys* including yam bean *(Pachyrrhizus erosus),* greengram *(Phaseolus aureus),* pigeonpea *(Cajanus cajan),* kenaf *(Hibiscus cannabinus),* okra *(Hibiscus esculentus),* tomato *(Lycopersicon esculentum),* sorghum *(Sorghum vulgare),* loofah *(Luffa cylindrica),* roselle *(Hibiscus sabdariffa),* and *Synedrella nodiflora.* These alternate hosts permit the yam nematode to survive in soil in the absence of yam, but only cowpea *(Vigna unguiculata)* and melon *(Cucumis citrullus)* have been found to actually increase soil populations of the nematode while *Zea mays* and tobacco are categorised as non-hosts (Adesiyan 1976). Use of resistant varieties should maximise and stabilize yields through their effects on nematode population dynamics. Crop yield depends upon the initial nematode density and the rate of reproduction, and the inherent insensitivity of the host. The value of a resistant variety, therefore, depends upon the interrelationships of the mechanism of resistance with the biology of the

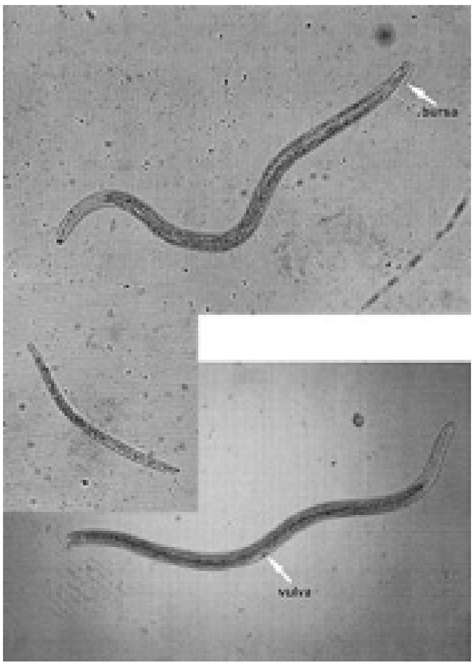
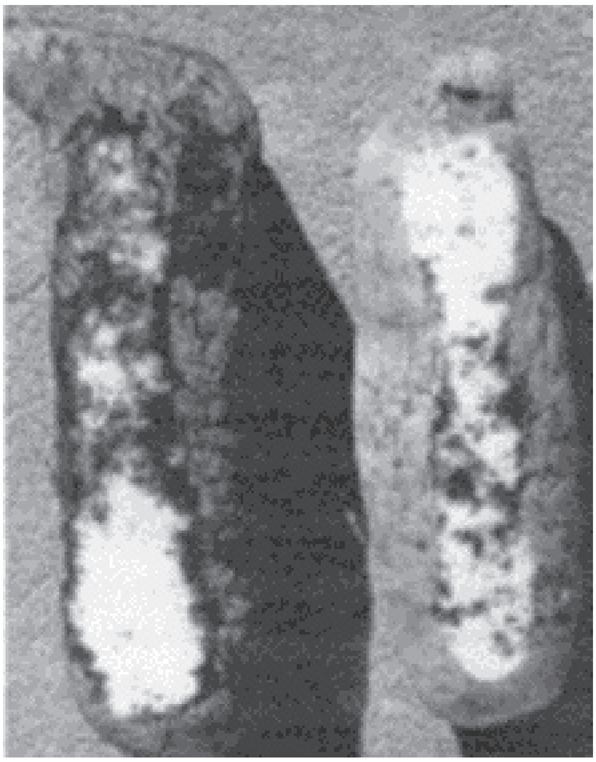


Fig 1. *Scutellonema bradys*, the yam nematode. A: young, B: male, C: female;



Plar 4. Dry rot of yams caused by *Scutellonema bradys*

Table 1. Selected crops screened for resistance to Scutellonema bradys.

Common name	Binomial	Cultivars	Source of material
White yam	Dioscorea rotundata Poir.	(i) TDr 87/00072 (hybrid) (ii) TDr 93-31 (Danacha) (iii) TDr 131 (Abi)	IITA
Water yam	Dioscorea alata L.	(i) TDa 85/00257 (hybrid) (ii) DAN 087 (Ominelu) (iii) TDa 92-2 (Sagbe)	IITA
Yellow yam	Dioscorea cayenensis Lamk.	Igangan	Ojoo market
Chinese yam	Dioscorea esculenta Lour-Burk.	(i) TDe 3041 (ii) TDe 2786 (iii) TDe 3037	IITA
Cocoyam	Xanthosoma sagittifolium (L.) Schott	Tania	Farmer/Ojoo Market
Sweet potato	Ipomoea batatas (L.) Lam.	TIS 6498	Farmer at U.I.
Maize	Zea mays L.	TZSR-W-1	IITA
Ginger	Zingiber officinale Rosc.	UG1 (Tafingiwa)	Makurdi Market
Pigeon pea	Cajanus cajan (L.) Verde.	Oyo white	IITA
Bambara nut	Vigna subterranea (L.) Verdc.	TVSU 155	IITA
Velvet beans	Mucuna pruriens (L.) Dc. var. utilis (Wall, ex Wight) Baker ex Burk.	IRZ	IITA

Table 2: Reaction of plants screened for susceptibility to S. bradys.

Hosts	Non-hosts
TDr 87/00072, TDr 93-31, TDr 131, TDa 85/00257, DAN 087, Me 3041, Me 3037, Me 2786, Igangan, Cajanus cajan, Vigna subterrenea, and Mucuna pruriense	TDa 92-2, Zea mays, Zingiber officinale, Xanthosoma sagittifolium and Ipomoea batatas

host and the nematode. Crops resistant to S. bradys suffered less damage or none. The resistant reaction is less harmful than the susceptible one, but, more importantly, the resulting suppression of nematode multiplication reduced damage. These resistant plants do have potential use in yam nematode management programs.

Conclusions

Visible symptoms of infection (dry rot) was observed on susceptible crops and tubers, while resistant crops and tubers showed none of these signs and symptoms.

Potentially, the most economical and effective method of controlling yam nematodes is the use of nematode-resistant plant varieties. The future looks bright for identifying new classes of pesticides from allelopathic plants to replace the dangerous synthetic chemicals used at present.

Table 3: Influence of initial number (Pi = 10000) of S. bradys on nematode reproduction in green-house screening for resistance

	Number of nematodes (S. bradys) at different Periods			
Variety	AH	4WAH	8WAH	Rate of nematode increase (RF) Pf/Pi
TDr 87/00072	2821b	10976a	26510a	9.4
TDr 93-31	2000e	9640d	18108d	9.1
TDr 131	2500c	9670c	22506c	9.0
TDa 85/00257	800g	4965f	7600f	9.5
DAN 087	1712f	6919e	14460e	8.4
TDa 92-2	0.0k	0.0j	0.0j	0
Igangan	2508c	9972b	24405b	9.7
TDe 3041	295i	1494h	3022h	10.2
TDe 2786	206j	994i	2461i	12.0
TDe 3037	525h	2109g	4976g	9.5
Cocoyam	0.0 k	0.0j	0.0j	0
Red Potato	0.0 k	0.0j	0.0j	0
Yellow Ginger	0.0 k	0.0j	0.0j	0
IRZ (M. pruriens)	3366a	-	-	0.3
TZSR-W-1 (maize roots)	0.0 k	-	-	0
TVSU155 (bambara nut roots)	2074d	-	-	0.2
Oyo White (pigeonpea roots)	2512c	-	-	0.3

Values are means of five replicates. Within experiments means followed by the same letter in vertical columns are not significantly (P=0.05) different as judged by Duncan's Multiple Range Test (DMRT). RF = Reproductive Factor, Pf = nematode population density at sampling date, Pi =initial nematode population density #/100g peel Dashes indicate data not collected

TDr = Tropical Dioscorea rotundata TDe = Tropical Dioscorea esculenta
TDa = Tropical Dioscorea alata TDc = Tropical Dioscorea cayenensis

AH = At harvest, WAH = weeks after harvest

Table 4: Reproduction of S. bradys in soil against initial nematode density, 180 days after planting, in resistance screening experiments.

Variety	Greenhouse	RF (Pf/Pi)	Field	RF (Pf/Pi)
TDr 87/00072	22976a	2.3	18422b	1.8
TDr 93-31	14001e	1.4	16500c	1.7
TDr 131	19971b	2.0	16015d	1.6
TDa 85/00257	8712g	0.9	9982g	1.0
DAN 087	10975f	1.1	9985g	1.0
TDa 92-2	2090L	2.1	3907h	0.4
Igangan	16980c	1.7	20400a	2.0
TDe 3041	5003i	5.0	10962f	1.1
TDe 2786	4991i	5.0	10062g	1.0
TDe 3037	6200h	0.6	11520e	1.2
Cocoyam	18n	1.8	10k	0
Red Potato	111m	0	154k	0
Yellow ginger	13n	1.3	10k	0
IRZ (M. pruriens)	14985d	1.5	18377b	1.8
TZSR-W-1 (maize roots)	5n	5.0	10k	0
TVSU 155 (bambara nut roots)	3962j	0.4	2381i	2.4
Oyo White (pigeonpea roots)	2200k	0.2	1266j	0.1

Values are means of five replicates. Within experiments means followed by the same letter in vertical columns are not significantly different as judged by Duncan's Multiple Range Test (DMRT). RF = Reproductive Factor, Pf = nematode population density at sampling date, Pi = initial nematode population density #/100 g soil

TDr = Tropical Dioscorea rotundata TDe = Tropical Dioscorea esculenta
TDa = Tropical Dioscorea alata TDc = Tropical Dioscorea cayenensis

Table 5: Influence of initial number (Pi = 10000) of *S. bradys* on nematode reproduction in field screening for resistance

Cultivar	Number of nematodes (*S. bradys*) at different periods			
	AH	4WAH	8WAH	Rate of nematode Increase RF) Pf/Pi
TDr 87/00072	3148b	11012a	25040a	8.0
TDr 93-31	1660e	8280d	21001c	12.7
TDr 131	2144d	10070b	23010b	10.7
TDa 85/00257	996h	3972f	10197e	10.2
DAN 087	1251g	6219e	14214d	11.4
TDa 92-2	0.0k	0.0j	0.0i	0
Igangan	2095d	9985c	24973a	11.9
TDe 3041	241j	1419h	3221g	13.4
TDe 2786	246j	10741	2383h	9.7
TDe 3037	481i	1964g	4974f	10.3
Tania	0.0k	0.0j	0.0i	0
Red Potato	0.0k	0.0j	0.0i	0
Yellow Ginger	0.0k	0.0j	0.0i	0
IRZ (M. pruriens)	7973a	-	-	0.8
TZSR-W-1(maize roots)	0.0k		-	0
TVSU155 (bambara nut roots)	1557f	-	-	0.2
Oyo White (pigeonpea)	2418c	-	-	0.2

Values are means of five replicates. Within experiments means followed by the same letter in vertical columns are not significantly (P=0.05) different as judged by Duncan's Multiple Range Test (DMRT). RF = Reproductive Factor, Pf = nematode population density at sampling date,
Pi = initial nematode population density #/100 g peel Dashes indicate data not collected
TDr = Tropical Dioscorea rotundata TDe = Tropical Dioscorea esculenta
TDa = Tropical Dioscorea alata TDc = Tropical Dioscorea cayenensis
AH = At harvest, WAH = weeks after harvest

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Influence of tuber harvest time and storage period on polyphenoloxidase activity and rate of browning of white yam (*Dioscorea rotundata*)

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Abstract

In this study, the effects of stage of maturity and storage time of yam tubers on polyphenoloxidase (PPO) activity, and rate of browning of tuber parenchyma were investigated. Five Nigerian traditional varieties of *Dioscorea rotundata* were evaluated during the vegetative cycle. Final harvesting was done when foliage senescence was observed; analyses on the tubers continued during the storage of yam tubers in ambient conditions for three months. The rate of browning of the tuber parenchyma did not show any definite trend throughout the vegetative cycle and storage period and the varieties also behaved differently from one another. The three sections (proximal, middle, and tail) of the tuber also did not influence the rate at which browning occurred in the parenchyma. It could be deduced that the rate at which the color of the tuber parenchyma changes from white to brown upon exposure to atmospheric air is not dependent on the age and length of storage period of the tuber, but could be an inherent attribute of the variety. PPO activity reduced in most of the varieties with an increase in the age of the yam plant and exhibited irregular behavior during storage.

Key words: White yam, polyphenoloxidase, rate of browning, starch granule

Introduction

Browning of crops during storage and processing is a significant problem in the food industry and the home and is believed to be one of the main causes of quality loss during post-harvest handling. Browning can cause deleterious changes in the appearance and organoleptic properties of the food product, resulting in reduced consumer acceptance (McEvily et al. 1992).

Browning in yam occurs at all stages of the tuber's existence as a result of the oxidation of phenolic constituents, such as o-dihydroxy or vic-trihydroxyphenolics, by a phenol oxidase present in the tissue (Anosike and Ayaebene 1981). Ozo and Caygill (1986) identified cyanidin 3-glucoside, (+)-catechine and accompanying procyanidins as substances probably involved in the enzymatic browning reaction. Some yam cultivars are characterized by browning reactions caused by the action of polyphenol oxidases on the polyphenolic compounds present in the tubers. This occurs during processing when the tubers are exposed to the air (Adamson and Abigor, 1980).

The browning reaction causes formation of an ugly brown or gray color, which polymerizes to form melanin responsible for off-flavors and sometimes bitterness in yam (Osagie 1992). This discoloration affects the organoleptic appeal of fresh or processed yam and reduces its acceptability. Browning index (BI) represents the purity of brown color and is reported as an important parameter in the processing of crops in which both enzymatic and non-enzymatic browning have been observed (Buera et al. 1986; Guerrero et al. 1996; Palou et al. 1999).

Materials and methods

Five Nigerian traditional varieties of Dioscorea rotundata were obtained from IITA for the experiments. TDr 131 (abi), TDr 99-12 (ehuru), TDr 99-13 (omiefun), TDr 99-3 (akwuki), and TDr 335 (sebureke).

Planting: Whole small tubers and tuber setts of various sizes (100 – 300 g) for each of the varieties were planted at IITA, Ibadan, Nigeria, in a randomized complete block design with three replications. The varieties were randomly allocated to plots with 130 plants/plot and arranged as 10 rows of 13 plants/row at 1 m × 1 m spacing.

Selection and harvesting: Dates of emergence of vines were noted and only those that emerged within the first 5 weeks after planting were tagged for subsequent sampling. Harvesting was done on a monthly basis from 4 months after planting, which coincided with 3 months after vine emergence (MAVE). Harvesting for each month was spread over 3 weeks for the three replicates (i.e., one replicate/week). From 4 to 10 of the plants tagged for sampling were harvested at random. The tubers were washed and laid out in the shade to air-dry. Final harvesting was done at 7 MAVE when there was complete senescence of the vines. Selected tubers from the final harvest were stored for 3 months inside net bags under ambient conditions in a storage barn made of bamboo shelves nailed to live poles whose leaves and a thatched roof provided adequate shade (a modification of the traditional storage structures common in Nigeria). Sampling of tubers for analyses was done on a monthly basis.

Sorting and preparation of tubers: Freshly harvested tubers were sorted into three classes: big (the biggest of the lot), medium (tubers of sizes between the biggest and the smallest) and small (the smallest of the lot). Three sections (proximal, middle and tail) of three tubers, which represented the three size categories, were cut open to expose the parenchyma. Single point measurements on the three tubers were made.

Determination of rate of browning: A Color-meter was used to measure the L*a*b* values of the flesh of freshly peeled yam tuber at 0 minute. Measurement was taken again after 10 mins. The BI was calculated to represent the purity of the brown color. Palou et al. (1999) explained in their report that it is as an important parameter in processes where enzymatic and non-enzymatic browning takes place. The BI of the yam flesh at 0 min and after 10 min was obtained from the calculation below:

$BI = [100 (x – 0.31)] / 0.172$
where $x = (*a + 1.75*L) / (5.645L + *a – 3.012*b)$

Δ BI was calculated as difference between the BI values after 10 min and the initial BI value (0 min)
Rate of browning $^{-min}$ (Δ BI/min) = Δ BI / 10 (min)

Determination of PPO activity: Crude polyphenol oxidase (PPO) was obtained by homogenizing 9 g of freshly peeled yam tissue in 45 ml of cold buffer (0.05 M sodium phosphate, pH 7.0) in Ace homogenizer at 0.42 g for 4 min. The homogenate was centrifuged at 75.75 g (4 oC, 10 min) and the supernatant was used as the source of crude enzyme (modified method of Omidiji and Okpuzor [1996].

The PPO activity of yam tissue was determined using 12.5 mM catechol as substrate, according to the modified method of Adamson and Abigor (1980). The assay medium contained 5.4 ml of 0.2 M sodium phosphate buffer, pH 7.0, containing 12.5 mM catechol, and 0.1 ml of crude enzyme extract, while the reference cuvette contained 5.4 ml of the buffer-catechol mixture and 0.1 ml of the crude enzyme extract which had been previously boiled and cooled. The change in absorbance at 440 nm was read after 90 s in a Spectronic 401 spectrophotometer (Milton Roy). One unit of PPO activity is defined as a change of 0.01 absorbance unit at 440 nm at room temperature (29±2 ^{o}C).

Results

Rate of browning: The rate of browning of the tuber parenchyma did not show any definite trend throughout the vegetative cycle and storage period (Table 1) while the varieties also behaved differently from one another. Difference in the portions of tuber examined also did not influence the rate at which browning occurred in the parenchyma (Table 2). The negative values obtained could be attributed to the sensitivity of the color meter. It could be deduced that the rate at which the tuber parenchyma changes from white color to brown upon exposure to atmospheric air is not dependent on the age and length of storage of the tuber, but could be an inherent attribute of the variety. Abass et al. (2003) also reported that there were no significant changes in the color indices as well as the BI measured on yam tubers' parenchyma (D. rotundata varieties) during storage. The mean values of the effect of the age of the plant and length of storage period on the rate of browning of the tuber parenchyma of five varieties are shown in Table 3.

Polyphenol oxidase activity: PPO activity of the yam varieties with age and length of storage of tubers is as shown in Figure 1. No result was indicated at 7

Table 1: Effect of age of plant and storage period on rate of browning (min^{-1}) of yam tuber parenchyma

Months after vine emergence (MAVE)	Months of storage	Variety				
		TDr 131	TDr 99-12	TDr 99-13	TDr 99-3	TDr 335
3		0.38abc	0.27b	0.45abc	0.18a	0.30ab
4		0.70a	0.37b	0.19bc	0.24a	0.03ab
5		0.64ab	0.07b	0.65a	0.34a	0.27ab
6		0.28abc	0.14b	0.24abc	0.32a	0.28ab
7		0.53abc	0.38b	0.04c	0.79a	1.20a
	1	0.18bc	0.13b	0.61ab	0.48a	0.31ab
	2	0.08c	2.52a	0.32abc	ND	-0.22b
	3	0.41abc	0.78b	0.24abc	ND	0.23ab

Means followed by the same letters along the column are not significantly different (P<0.05).

ND – Not determined

Table 2: Variation in rate of browning (min^{-1}) of different portions of yam tuber parenchyma

Tuber portion	Variety				
	TDr 131	TDr 99-12	TDr 99-13	TDr 99-3	TDr 335
Head	0.57a	0.65a	0.36a	0.33a	0.19a
Middle	0.38ab	0.15a	0.37a	0.43a	0.49a
Tail	0.28b	0.37a	0.24a	0.42a	0.30a

Means followed by the same letters along the column are not significantly different (P<0.05).

Table 3: Mean effect of age of plant and storage period on rate of browning (min^{-1}) of tuber parenchyma of five varieties

Months after vine emergence (MAVE)	Months of storage	Rate of browning (min^{-1})
3		0.30a
4		0.28a
5		0.18a
6		0.05a
7		0.53a
	1	0.29a
	2	0.36a
	3	0.35a

Means followed by the same letters along the column are not significantly different (P<0.05).

(MAE) due to a logistics problem. Results obtained showed a decreasing trend in values during growth to the month of October (6 MAE), while the varieties showed irregular behavior at storage time. A similar decrease in activity was reported during the development of medlar fruit (Aydin and Kadioglu, 2003) and in Cajanus cajan leaves (Mukherjee and Rao, 1993). Ikediobi and Oti (1983) also reported a steady decrease of PPO activity during the storage of D. rotundata tubers. However, the activities of phosphorylase, hexokinase, glucose-6-phosphate, and alcohol dehydrogenase in D. rotundata increased with the age of tubers (Ugochukwu et al. 1977).

Adamson and Abigor (1980) and Anosike and Ayaebene (1981) associated yam tissue browning with PPO activity. Omidiji and Okpuzor (1996) reported that only 40% of browning in D. rotundata is due to PPO activity while the remainder is non-enzyme mediated. There was no observed correlation between the rate of browning and PPO activity. This might

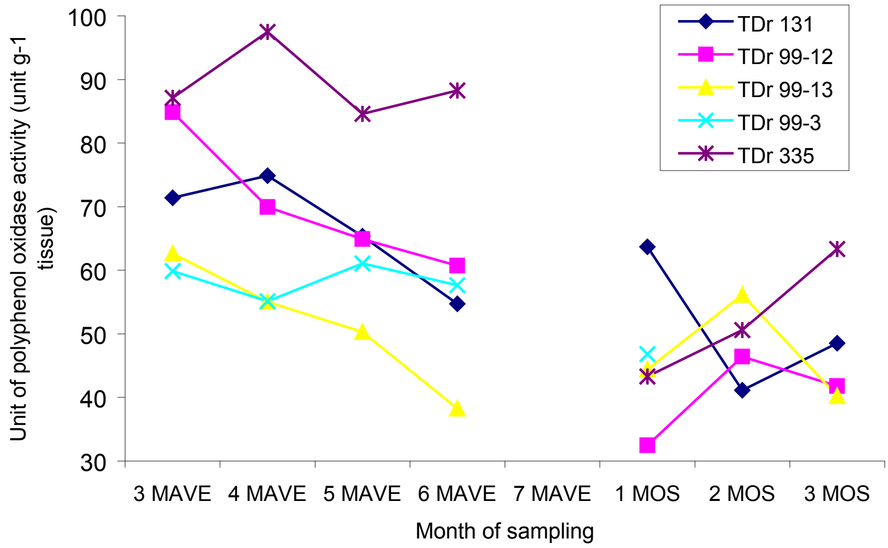

Fig. 1: Polyphenol oxidase activity of tubers with age and length of the storage period

be due to the short time (10 min) used for the study of rate of browning of the tuber parenchyma in this work.

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Effect of pre-treatment on sweet-potato flour for cookies production

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Abstract

The sweet-potato flour was produced by varying the blanching temperature from 60°C, 70°C, 80°C, to 90°C. Sweet-potato samples were blended with wheat flour and other ingredients to produce cookies. The proximate analysis, functional properties, and pasting properties were carried out on the pre-treated sweet-potato flour; physical characteristics and sensory evaluation of the cookies were determined. Results showed that there were no significant differences ($P < 0.05$) in the bulk densities, pasting time, and fat content of the sweet-potato flour samples. There were significant differences ($P > 0.05$) in the physical analysis, such as width, thickness, weight, and spread ratio of sweet-potato-wheat cookies. No significant differences were observed in the texture from sensory evaluation of the cookies though there were significant differences in the color, taste, and aroma.

Key words: Sweet-potato, pre-treatment, flour, cookies, proximate

Introduction

Sweet-potato (Ipomoea batatas L) is the seventh most important food crop in the world. It is grown in many tropical and subtropical regions. Among the world's major food crops, sweet-potato produces the highest amount of edible energy/ha/day (Horton and Fano, 1985). Sweet-potato flour can serve as a source of energy and nutrients (carbohydrates, beta-carotene (provitamin A), minerals (Ca, P, Fe, and K), and can add natural sweetness, color, flavor, and dietary fiber to processed food products (Woolfe 1992). Because of the distinct properties, the use of sweet-potato flour in the preparation of bread is restricted. Biscuits are baked dry products, usually with a golden brown crust and crispy texture (Fellows 1997).

Wheat flour is generally used for biscuit production with other ingredients, such as margarine (shortening), sweeteners (sugar), leavening agent, eggs, milk, salt, flavorings (Hui 1992). Recently, the use of composite flour was evolved in the bakery world for cakes and biscuits. Composite flour is the name given to a combination of two or more types of flour in a specific ratio for baking. Wheat flour is lacking in some essential amino acids, such as lysine, methionine, and threonine (Rayar et al. 1990). The deficient nutrients can be supplemented through the use of composite flour. Gluten is present only in wheat flour; the use of composite flour changes the texture of biscuits especially in types, where strength is dependent on some appropriate level of gluten development (Okaka and Anjekwu 1980). The availability of our local crops, their reduction in postharvest losses through the processing of some into flour and the cost of the importation of wheat flour, led to the use of sweet-potato flour (Ukhum and Ukpebor 1991). Hence, the main objective is to study the effects of pre-treatment on sweet-potato flour for cookies production.

Materials and methods

The variety of sweet-potato that was used was the yellow skinned type with cream flesh purchased from Oke-odo market in Lagos. Other ingredients, such as salt, sugar, margarine, baking powder, milk, vanilla flavoring, wheat flour, and eggs, were also purchased from the same market.

Production of sweet-potato flour. Sweet-potato flour was produced following the method described by Adeleke and Odedeji 2010. Sweet-potato tubers were sorted and washed to remove sand, dirt, and other adhering materials. The cleaned tubers were peeled using a sharp stainless steel knife and sliced using a kitchen slicer to obtain a sliced thickness of 6 ± 1 mm. The slices were then washed and placed in a sieve to remove excess water. The slices were blanched at different temperature (60°C, 70°C, 80°C, and 90°C) for 5 min. to inactivate the enzyme that causes browning before being dried in the cabinet dryer. The dried slices were milled in a disc attrition machine to obtain flour. The flour was then sieved, packed in a polythene bag, and stored at ambient temperature (Adeleke and Odedeji 2010).

Cookies formulation. The formulation for standard biscuits or cookies according to Oyewole et al. (1996) was followed for the production of sweet-potato cookies: wheat flour (200 g), margarine (100 g), sugar (70 g), baking powder (2 g), salt (0.2 g), vanilla flavoring (0.2 g), milk (100 g), egg (48.30 g).

Production method. Sugar (70 g) was added to margarine (100 g) in a Kenwood Mixer and mixed at medium speed until fluffy (for about 12 min). Egg (48.30 g) and milk (50 g) were added while mixing and then mixed for approximately 30 min. Sifted flour (200 g), baking powder (2 g), and vanilla flavoring (0.2 g) were slowly added into the mixture. The mixture was kneaded until dough formation. It was then rolled on a flat board sprinkled with flour to a uniform thickness of about 0.4 cm using a wooden rolling pin and guiding stick. Circular cookies of 5.8 – 6 cm diameter were cut, placed on oiled baking trays, and baked at 160°C for about 15 min.

Analytical determinations. The moisture, protein, ash, crude fiber, and fat contents of the samples were determined using the AOAC (2000) and Njintang et al. (2008) methods. The starch and total sugars content were determined using a colorimetric method (Dubois et al. 1956). Absorbance was read at 490 nm using a spectrophotometer (model Spectronic 601, Milton Roy Company, USA). Swelling power and solubility were determined by the method described by Leach et al. (1959). Water absorption capacity (WAC) was determined using the method described by Sosulski (1962). Bulk density was determined using the method of Wang and Kinsella (1976).

Pasting properties were determined using a Rapid Visco Analyser (RVA) (model RVA 3D+; Network Scientific, Australia). The sample was turned into slurry by mixing 3 g with 25 ml of water inside the RVA can. This was inserted into the tower which was then lowered into the system. The slurry was heated from 50 to 95°C and cooled back to 50°C within 12 min; the can was rotated at a speed of 160 rpm with the continuous stirring of the contents with a plastic paddle. Parameters estimated were peak viscosity, setback viscosity, final viscosity, pasting temperature, and time to reach peak viscosity.

Physical evaluation of cookies. The weights, thickness, width, and spread ratio were measured before and after baking. A micro meter screw gauge was used to determine the thickness of the cookies and the spread ratio was calculated as spread ratio / width.

Sensory evaluation of cookies. Ten panelists who were familiar with cookies were used for the sensory evaluation. Evaluations were made on a 9 point hedonic scale with 9 = like extremely and 1 = dislike extremely. The cookies were assessed for color, aroma, texture, and overall acceptability.

Statistical analysis. Each analytical determination was carried out in three replicates. Data were subjected to analysis of variance (ANOVA) using SAS version 8e software (SAS Institute Inc., Cary, NC, USA) at $P < 0.05$. Means were separated using Duncan's Multiple Range Test.

Results and Discussion

The effects of pretreatment on the chemical properties of sweet-potato flour are presented in Table 1. There was a significant difference at the 5% level in the moisture content of the blanched sweet-potato flour. Moisture content values ranged from 5.11 to 7.54%, showing the effectiveness of drying. The blanched sweet-potato flours are at the minimum limit of moisture content for flour (Adeleke and Odedeji 2010). The moisture content goes a long way in suggesting the shelf life of the product. The moisture content of all the flours was below the 10% stipulated standard of the revised regulation of the Standard Organization of Nigeria (Sanni et al. 2004). There was significance difference in the protein content of the sweet-potato flour at 5% level; values ranged from 6.50 to 7.78%. Flour from 90 °C had the lowest protein value and this is due to the naturally low protein content of sweet-potato roots (FAO 1990). The values of ash ranged from 2.42 to 2.70% and the crude fiber content of the sweet-potato flour was between 2.35 and 2.85%. At the 5% level, there was a significance difference between the ash values of the flours that were generally low. High ash and crude fiber content in food depicts those materials that are indigestible in the human body. There was a significant difference between the starch content of the samples; values ranged from 26.93 to 35.10%. The starch content was generally high, because the main constituent of all the flours used was carbohydrate. There was no significant difference between the sugar content of the sweet-potato flours since flours naturally contain little or no sugar and the quantity of sugar used in baking the cookies were uniform. At the 5% level, there was no significance difference between the crude fat values of the sweet-potato flours which ranged from 3.54 to 3.89%.

Table 2 shows the results of functional properties of blanched sweet-potato flour. At the 5% level, there was no significance difference in the bulk densities of the varying temperature. Bulk densities ranged from 120 to 150. This is usually affected by the particle size and density of the flour and it is very important in determining the packaging requirement, materials handling and application in wet processing in the food industry (Karuna et al. 1996). There were significant differences in the water absorption of the blanched sweet-potato flours with the sample at 60°C having the highest value of 257.88%. There were significant differences in the swelling power and solubility of the samples. Swelling power is an indication of the absorption index of the granules during heating (Loos and Graham, 1981). Swelling property indicates the power holding capacity and has generally been used to demonstrate differences between various types of starches and to examine the effect of starch modification (Crosbie 1991). The swelling power of flours is often related to their protein and starch contents (Woolfe 1992). Higher protein contents in flour may cause the starch granules to be embedded within a stiff protein matrix which subsequently limits the access of the starch to water and restricts the swelling power (Singh et al. 2003). The swelling power and solubility provide evidence of the magnitude of interaction between starch chains within amorphous and crystalline domains. The extent of this interaction is also influenced by the amylose to amylopectin ratio, and by the characteristics of amylose/amylopectin in terms of molecular weight/distribution, degree and length of branching and conformation (Hoover 2001).

Results of the pasting properties of the blanched sweet-potato flours are shown in Table 3. When starch-based foods are heated in an aqueous environment, they undergo a series of changes known as gelatinization and pasting. These are two of the most important properties that influence quality and aesthetic considerations in the food industry, since they affect texture and digestibility as well as the end use of starchy foods (Adebowale et al. 2005). There were no significant differences in the pasting profiles of the blanched sweet-potato flours except for the pasting temperature. The peak viscosity which is the ability of starches to swell freely before their physical breakdown (Sanni et al. 2004) ranged from 58.36 to 97.46 RVU. It occurs at equilibrium between swelling (which increases velocity) and granule rupture and alignment (which cause its decrease). Sample 80°C had the highest peak viscosity (97.46 RVU) and sample 60°C had the lowest of 58.36 RVU. Jin et al. 1994 reported that a high hot paste viscosity generally represents low cooking losts and superior eating quality. Newport Scientific (1995) indicated that starches with low paste stability and high breakdown have very weak cross-linking within granules. This indicates that there is less stability to paste breakdown. The trough, which is the minimum viscosity value in the constant temperature phase of the RVU profile and measures the ability of paste to withstand breakdown during cooling, ranged from 25.84 to 65.25 RVU. Sample 90°C had the highest trough value of 40.21RVU and sample 60°C had the lowest of 7.08 RVU. The pasting temperature is the temperature at which irreversible swelling of the starch granules occur, leading to the formulation of a viscous paste in an aqueous solution.

Table 4 shows the result of the physical properties of sweet-potato cookies. The weight of the cookies before and after baking shows significance differences ($P < 0.05$), this was due to the thickness of the paste that has no gluten, the stretching ability is low, so the sweet potato paste was thicker than wheat paste while it was rolled into sheets to avoid breakage. The spread ratio after baking shows significance differences ($P < 0.05$) among the cookies samples.

Table 5 shows the result of the sensory analysis of the cookies. There was no significance difference in the texture of the samples ($P<0.05$). The taste, color, aroma, and overall acceptability show that there was a significance difference among the samples. Sample 60°C shows wide significance differences ($P < 0.05$) in the overall acceptability. Sweet-potato cookies made from flours blanched at 60°C are most acceptable, cookies from flours made from 70°C and 90°C blanching temperatures and the control were slightly or partially accepted. Respondents were neither like nor dislike sweet potato cookies made from flour at 80 °C blanching temperature.

Table 1: Chemical properties of sweet-potato flour.

Parameters	60 °C	70 °C	80 °C	90 °C	SEM
Fat	3.78a	3.89^{a}	3.54^{a}	3.65^{a}	0-08
Protein	6.79^{c}	7.34^{b}	7.78^{a}	6.50^{d}	0.19
Ash	2.70^{a}	2.42^{b}	2.51^{b}	2.44^{b}	0.04
Sugar	1.70^{b}	2.05^{a}	1.69^{b}	1.20^{c}	0.11
Starch	29.87^{b}	26.93^{d}	35.10^{a}	28.88^{c}	1.14
Crude fiber	2.35^{c}	$2.45b^{c}$	2.60^{b}	2.85^{a}	0.07
Moisture	6.90^{b}	7.54^{a}	5.24^{c}	5.11^{c}	0.40

Mean value with different superscripts in the same row are significantly different (P<0.05)

Table 2: Functional properties of sweet-potato flour at different blanching temperature

Parameters	60 °C	70 °C	80 °C	90 °C	SEM
Swelling power	7.92^{a}	8.39^{b}	8.70^{a}	8.20^{c}	0.14
WAC	257.88^{a}	209.85^{c}	175.94^{d}	38.28^{b}	11.68
Solubility	19.69^{d}	20.21^{b}	19.97^{c}	20.46^{a}	0.11
Bulk density	1.50^{a}	1.50^{a}	1.30^{a}	1.20^{a}	0.55

Mean value with different superscripts in the same row are significantly different (P<0.05

Table 4: Physical characteristics of sweet-potato cookies

Parameters	60 °C	70 °C	80 °C	90 °C	Control
Thickness	6.06^{b}	8.03^{a}	6.06^{b}	4.07^{c}	0.53
Weight	11.55^{a}	12.40^{a}	13.10^{a}	7.25^{b}	0.95
Spread ratio	8.30^{b}	5.85^{d}	7.46^{c}	10.12^{a}	0.58
Width	5.05^{a}	4.70^{b}	4.55^{c}	4.15^{c}	0.12

Mean value with different superscripts in the same row are significantly different (P<0.05)

Table 5: Sensory analyses of sweet-potato cookies

Parameters	60 °C	70 °C	80 °C	90 °C	Control
Color	7.20^{a}	6.40^{b}	5.80^{b}	6.40^{b}	6.40^{b}
Taste	7.70^{a}	5.40^{b}	5.20^{b}	5.10^{b}	6.60^{ab}
Aroma	6.60^{a}	5.70^{bc}	5.30^{c}	5.50^{c}	6.30^{ab}
Texture	6.80^{a}	6.40a	6.00^{a}	6.10^{a}	6.20^{a}
Overall Acceptability	7.50^{a}	6.30^{b}	5.50^{c}	5.80^{bc}	6.40^{b}

Mean value with different superscripts in the same row are significantly different (P<0.05)

Table 3: Pasting properties of sweet-potato flour at different blanching temperature

Parameters	60 °C	70 °C	80 °C	90 °C	SEM
Peak1 (RVU)	58.38^{d}	73.83^{b}	97.46^{a}	66.05^{c}	5.54
Trough1 (RVU)	7.08^{c}	8.59^{c}	36.13^{b}	40.21^{a}	5.76
Break down (RVU)	51.29^{b}	65.25^{a}	61.34^{b}	25.84^{d}	5.81
Final viscosity (RVU)	12.33^{c}	14.33^{c}	49.75^{b}	54.58^{a}	7.38
Set back (RVU)	5.25^{b}	5.75^{b}	13.63^{a}	14.38^{a}	1.61
Peak time (min)	3.90^{b}	3.85^{c}	4.04^{b}	4.22^{a}	0.06
Pasting temp (°C)	50.20	50.23^{a}	50.20^{a}	50.25^{a}	0.03

Mean value with different superscripts in the same row are significantly different (P<0.05)

Conclusion

The study has shown that different blanching temperatures have an effect on the quality of flour produced, hence the different flours produced from the varying blanching temperatures differed in quality. The functional properties have effects on the blanched flours. Flour produced at 60 °C had the highest water absorption capacity and this gave it a higher affinity to absorb water during production. Sweet-potato cookies made from flours blanched at 60 °C were most acceptable. Sweet-potato is an acceptable alternative crop that could be used in the production of cookies.

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Predicted changes in suitability and agro climatic factors due to climate change for yam production in Nigeria

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Abstract

Monthly data outputs on rainfall and temperature from 18 SRES models for emission scenario obtained from CIAT and *w*hite yam production extracted from FAO's Ecocrop were utilized to predict changes in suitability and effect of agro climatic change on yam production in Nigeria. The average outputs for all 18 models were used for calculating area changes to compare the 1951-2000 period with the predicted 2040-2069. The prediction showed that there will be increase of 10% by 2050 on the areas with "Excellent" suitability for growing white yam as a result of predicted increases in rainfall amounts in the north as well as rising temperatures in mid altitude and highland areas of Nigeria. For the areas classified as "Very Suitable", "Suitable" and "Marginal" there were only slightly reductions in areas with 3, 1 and 8% respectively as compared to the climate averages of 1951 to 2000. The "Very Marginal" showed the highest area increase (175%) as it went from 37,000 km^2 to over 65,000 km^2 for the 2050 period when compared to current long term averages. The predicted average annual temperature changes showed that all states are going to face increased temperatures. The predicted increases in temperature in the northern parts of the country were higher than coastal areas with a standard deviations between 0.01 and 0.11 C. In order to properly relate impact of changing climate on productivity and yield and the economic and food security implications time series of production and yield data and the respective climate data would be needed to derive linear or other relations.

Key words: Yams, *Dioscorea rotundata* agro climatic change

Introduction

Yam, genus Dioscorea, family Dioscoreaceae, are economically an important multi-species crop for sustainable food production in tropical and subtropical regions (Ayensu and Coursey 1972). Yam serve as a valuable source of food across Africa, Asia, South America, the Caribbean and the Pacific 1976)

Out of about 600 species known, six are grown in Nigeria: (D. rotundata (white Guinea yam), D. alata (water yam), D. cayenensis (yellow yam), D. dumetorum, (trifoliate yam), D. bulbifera (aerial yam), and D. esculenta (Chinese yam). However, the most important food species are D. rotundata, indigenous to West Africa, and D. alata introduced from Asia to Africa during the sixteenth century. The variety most cultivated and consumed is D. rotundata and it also has the highest market value owing to the superior suitability of its tubers for preferred food uses in West Africa.

Yam constitute an important source of food and income and play a major role in socio-cultural life for a wide range of smallholder households. Nigeria is the world's largest producer with an estimated 35 million tonnes in 2008 grown on 3.1 million ha (FAO, 2011).

Yam play an important role as a food and cash crop for millions of consumers and hundreds of thousands of small-scale producers in Nigeria and some other West African countries. It is estimated to provide 60 million people with an average of 200 cal/day from Côte d'Ivoire to Cameroon (Nweke et al., 1991) so it is an important food security crop. It is also clearly a major source of revenue for many people, including a good proportion of women as producers, processors and traders. Production is carried out in three major ecological zones in Nigeria: the northern section of the rainforest, the southern Guinea or derived savanna, and the southern portion of the northern Guinea savanna. Originally, yam was a rainforest crop grown throughout the West African forest zone. In Nigeria, these yam ecological zones extend from 5^{o}N latitude up to 9^{o}N latitude. These areas predominantly have a monomodal rainfall distribution with two marked seasons; the rainy season (April to September) and the dry season (October to March). Production has been shifting northwards from the humid forest zone, (4^{o}N latitude) to the subhumid Guinea savanna ecological zones, between 8 to l0^{o}N latitude (Manyong et al. 1996).

Yam are essentially a tropical crop, and require good fertile soil, adequate and well distributed rainfall, and considerable labour input for agronomic operations such as land preparation, planting, staking, weeding, and training the vines.

Being a crop of the more humid and subhumid areas yam has higher dependency on the amount of rainfall and is more vulnerable to drought compared with crops such as cassava. Climatic factors (soil moisture, temperature, light, and photoperiod) affect the growth and performance of yam.

Yam require rainfall for at least 5 of their 8 months of growth in the field. The distribution of rainfall is more important than the volume. Yam grow better in areas that have l,000-1,500 mm of rain well distributed over a period of 6 to 7 months in the cropping season (Onwueme, 1975). Yam require water throughout the active growth period for vine and leaf development, tuber initiation and bulking; the most critical stages are at tuber initiation and bulking. Moisture stress affects yam more when intercropped. Moisture stress has also been reported to delay tuber initiation in water yam (Onwueme 1975).

Africa is predicted to be the continent most vulnerable to the negative effects of climate change. At the same time it has the lowest adaptive capacity worldwide because of developmental challenges (Magrath, 2006, Stern, 2006, Boko et al., 2007, Collier et al., 2008, Eriksen et al., 2008). Higher temperatures and changes in rainfall patterns and intensity are expected to have impacts on crop production through higher pest and disease pressure, drought as well as floods, and increased water erosion (Rosenzweig et al., 2001, Fields, 2005, FAO, 2005, Orindi and Murray, 2005, Simms et al. 2005, Nyong and Niang-Diop, 2006, Easterling et al. 2007, Boko et al. 2007, Lobell et al. 2008, Battisti and Naylor, 2009, Burke et al., 2009, Gregory et al., 2009, Mertz et al., 2009; Smith et al., 2009, Thornton et al. 2009). Temperature increases due to climate variability that are already being monitored are expected to have serious impacts on crop yields as they are an important factor for production variations (Lobell and Burke, 2008, Battisti and Naylor, 2009). Many areas in Africa are predicted to receive less rain but others such as parts of East Africa could receive more, which is expected to fall at higher intensities (Boko et al., 2007). Some studies also predict decreasing rainfall for East Africa (Funk et al., 2008) Climate change is expected to have serious negative impacts on food security for large populations in Africa through reduced yields and also on the economy of many States that are largely dependent on agriculture (Warren et al, 2006. FAO, 2007; Lobell et al., 2008; Brown and Funk, 2008). Owing to the high dependency of African cropping systems on rainfall and the low capacity for adaptation, the impact of increased climate stresses is expected to be higher than on other continents (Challinor et al., 2007, Funk et al., 2008). Jones and Thornton (2003) predicted yield losses of 10-20% in many areas of Africa by 2050 as a result of increasing temperatures and declining rainfall.

Materials and Methods

The climate data used were obtained from CIAT and are described in Ramirez and Jarvis (2008). The data represent an estimated average of the time span yet to come. Monthly data outputs on rainfall and temperature from 18 SRES models for the emission scenario A2 were utilized. Emission scenarios each represent a possible future with differences in social, political, environmental and technological developments in global societies. The A2 scenario is commonly referred to as “business as usual” with no reduction in carbon emissions and is considered to be a medium-high scenario. It is defined by high global population estimates, no efforts to reduce global warming, high energy use, and a more regional approach to solving social and environmental issues (Nakicenvoic et al., 2000) Models used were: BCCR-BCM 2.0, CCCMA-CGM2, CCCMA-CGCM3.1 T47, CCCMA-CGCM3.1 T63, CNRM-CM3, IAP-FGOALS-1.0G, GISS-AOM, GFDL-CM2.1, GFDL-CM2.0, CSIRO-MK3.0, IPSL-CM4, MIROC 3.2-HIRES, MIROC 3.2-MEDRES, MIUB-ECHO-G, MPI-ECHAM5, MIUB-ECHO-G, MPI-ECHAM5, MRI-CGCM2.3.2A.,NCAR-PCM1,UKMO-HADCM3. The data was downscaled to 2.5 min (ca 5 km) resolution using an empirical statistical approach. For this, linear or other relationships are established between historical observed climate data at local scales such as meteorological station measurements and climate model outputs. ArcGIS software (Ormsby et al., 2009) was used to calculate averages and standard deviations of model outputs for all 18 models. Thresholds of climatic parameters for the suitability calculations for *D. rotundata* Poir., commonly known as white yam, were extracted from FAO's Ecocrop database (FAO, 2011) that is included in the DIVA Gis (Hijmans et al. 2005) software utilized. Ecocrop uses monthly rainfall and temperature values to calculate the suitability of a given location for the crops in the Ecocrop data base. The outputs for all 18 models were averaged and the average used for area change calculations comparing the period 1951-2000 with the predictions for 2040-2069. The environmental parameters utilized in DIVA GIS for *D. rotundata* Poir. were used as shown in Table 1.

Changes in rainfall amount were mapped comparing the worldclim 1.4 dataset (Hijmans et al, 2005b) for average annual rainfall covering the period 1951-2000 to the datasets provided by Ramirez and Jarvis (2008) as mentioned above. Both were available at a resolution of 2.5 minutes.

Results

Changes in suitability. The suitability changes as calculated with DIVA-GIS showed that the areas with "Excellent" suitability for growing white yam are predicted to increase by 10% for the 2050 period (see Table 2). This change brought about by predicted increases in rainfall amounts in the North as well as rising temperatures in the mid-altitude and highland areas in the East. Areas classified as "Very Suitable", "Suitable" and "Marginal" changed only slightly with 3, 1 and 8% reductions compared with the climate averages from 1951 to 2000. The "Very Marginal" category showed the highest area increase as it went up by 175% from 37,000 km^2 to over 65,000 km^2 for the 2050 period compared with current long-term averages. This additional area gain came mainly from the previously "Unsuitable" areas because of the increases in rainfall in the northern parts of the country. By 2050 the "Unsuitable" areas are predicted to be reduced by 72%. Standard deviations of the rainfall means of the 18 models calculated were up to 37% for some areas.

Predicted temperature and rainfall changes. Analyzing the predicted annual temperature changes averaged from the outputs of the 18 GCMs to State areas in Nigeria showed that all States are going to face increased temperatures (see Table 3). The range of average increased temperatures for States varied between 2.0 and 2.9^{o}C, the lowest being Bayelsa and Rivers and the highest being Borno, Jigawa, Kano, Katsina and Yobe. Generally predicted increases in the northern parts of the country were higher than in the coastal areas. Standard deviations between the 18 models averaged for the predicted temperatures varied between 0.01 and 0.11^{o}C.

Average annual rainfall amounts for most States increased slightly when predicted future rainfall amounts as an average of 18 GCM models for 2040-2069 were compared with the average historic rainfall from 1951 to 2000 (see Table 4). The range of differences expressed in mm was from +90 to 2mm. Standard deviations calculated for the States, however, were high in comparison and indicated considerable variation among some of the model outputs.

Figure 2 shows the predicted rainfall changes for the 18 models utilized for the whole country compared with the current long-term average (1951-2000) shown in Figure 1. Most areas of the country (see Fig 3.) except the coastal areas of the south west including the Niger Delta would experience slight increases, between 1 and 10%, according to the predictions of the 18 models.

Table 1. Ecocrop parameters used for the suitability calculations with Diva

Parameter	Definition	Values
Gmin	Minimum length of growing season (days)	180
Gmax	Maximum length (days)	300
KTMP	Absolute temperature that will kill the plant (^{o}C)	9
TMIN	Minimum average temperature at which the plant will grow (^{o}C)	15
TOPMN	Minimum average temperature at which the plant will grow optimally (^{o}C)	25
TOPMX	Maximum average temperature at which the plant will grow optimally (^{o}C)	35
TMAX	Maximum average temperature at which the plant will cease to grow (^{o}C)	38
Rmin	Minimum rainfall (mm) during the growing season	800
Ropmin	Optimal minimum rainfall (mm) during the growing season	1,000
Ropmax	Optimal maximum rainfall (mm) during the growing season	1,500
Rmax	Maximum rainfall (mm) during the growing season	3,000

Table 2.) Predicted suitability area changes for white yam in Nigeria.

Class	Current (km^2)	2050 (km^2)	% change
Unsuitable	226,768	162,160	72
Very Marginal	37,477	65,527	175
Marginal	48,830	45,024	92
Suitable	66,596	65,912	99
Very Suitable	90,690	87,804	97
Excellent	452,637	496,571	110

The south western coastal areas would experience a slight decrease of up to -2% but when the generally high annual precipitation in the area is considered this can be of minor importance. A relatively small area in the north east (mainly Kebbi State) would experience increases between 20 and 30% according top the predictions. Standard deviations for this spot, however, are also high with values between 100 and 200 mm. The area of highest differences between the outputs of the 18 models expressed through the standard deviations was in the south west bordering Benin Republic mainly in Oyo State but also the

Table 3.) Predicted temperature changes in Nigeria averaged for Federal states

State	Average Temperature 1951-2000 18 models (°C)	Average temperature 2040-2069 18 models (°C)	Average temperature SDEV 18 models (°C)	Average temperature Difference 18 models (°C)
Abia	26.4	28.5	0.03	2.1
Abuja FCT	26.6	29.1	0.02	2.5
Adamawa	26.2	28.8	0.07	2.6
Akwa Ibom	26.6	28.6	0.02	2.1
Anambra	27.0	29.2	0.02	2.2
Bauchi	25.7	28.4	0.11	2.7
Bayelsa	26.7	28.7	0.02	2.0
Benue	26.8	29.2	0.04	2.4
Borno	26.3	29.0	0.09	2.8
Cross River	26.5	28.7	0.05	2.2
Delta	26.7	28.7	0.03	2.1
Ebonyi	27.4	29.7	0.02	2.2
Edo	26.2	28.4	0.03	2.2
Ekiti	25.0	27.3	0.02	2.3
Enugu	26.3	28.6	0.02	2.2
Gombe	25.7	28.4	0.05	2.7
Imo	26.4	28.5	0.02	2.1
Jigawa	26.8	29.7	0.07	2.8
Kaduna	25.1	27.7	0.10	2.6
Kano	25.9	28.7	0.08	2.8
Katsina	25.9	28.6	0.10	2.8
Kebbi	27.8	30.4	0.11	2.7
Kogi	26.3	28.6	0.03	2.3
Kwara	26.7	29.1	0.05	2.4
Lagos	27.2	29.3	0.01	2.1
Lake Chad*	27.2	30.1	0.02	2.9
Nasarawa	27.0	29.4	0.04	2.5
Niger	27.1	29.6	0.08	2.5
Ogun	27.1	29.3	0.04	2.2
Ondo	26.1	28.3	0.03	2.2
Osun	26.1	28.4	0.03	2.3
Oyo	26.4	28.7	0.04	2.3
Plateau	25.6	28.1	0.04	2.6
Rivers	26.6	28.6	0.02	2.0
Sokoto	28.2	30.9	0.06	2.7
Taraba	26.1	28.6	0.07	2.5
Yobe	26.1	28.9	0.06	2.8
Zamfara	26.6	29.3	0.08	2.7

* Lake Chad refers to Eastern Borno State

Table 4.) Predicted rainfall changes in Nigeria averaged for federal states

State	Average annual Rainfall 1951-2000 18 model, a2a (mm)	Average annual rainfall 2040-2069 18 models, a2a (mm)	SDEV 18 models a2a (mm)	Diff. in (mm)	Diff in (%)
Abia	2,204	2,205	63	1	0.0
Abuja FCT	1,297	1,378	106	81	6.2
Adamawa	1,039	1,091	78	52	5.0
Akwa Ibom	2,722	2,720	70	-2	-0.1
Anambra	1,808	1,827	64	19	1.1
Bauchi	924	980	68	56	6.1
Bayelsa	3,163	3,166	89	2	0.1
Benue	1,477	1,528	81	52	3.5
Borno	608	650	61	42	6.9
Cross River	2,281	2,287	68	6	0.3
Delta	2,492	2,495	74	3	0.1
Ebonyi	1,892	1,911	66	18	1.0
Edo	1,751	1,778	81	26	1.5
Ekiti	1,314	1,369	136	55	4.2
Enugu	1,686	1,712	71	26	1.5
Gombe	882	928	72	45	5.1
Imo	2,172	2,176	63	4	0.2
Jigawa	619	656	49	37	6.0
Kaduna	1,252	1,324	93	73	5.8
Kano	825	869	61	44	5.3
Katsina	755	803	64	48	6.4
Kebbi	873	958	100	85	9.7
Kogi	1,271	1,327	99	57	4.5
Kwara	1,169	1,259	139	90	7.7
Lagos	1,636	1,658	123	22	1.3
Lake Chad	324	367	56	43	13.3
Nasarawa	1,338	1,406	93	67	5.0
Niger	1,156	1,224	102	67	5.8
Ogun	1,372	1,420	172	49	3.6
Ondo	1,640	1,673	109	32	2.0
Osun	1,340	1,402	175	62	4.6
Oyo	1,181	1,269	209	88	7.5
Plateau	1,184	1,244	82	60	5.1
Rivers	2,798	2,800	77	2	0.1
Sokoto	622	678	70	56	9.0
Taraba	1,286	1,335	65	49	3.8
Yobe	534	562	51	27	5.1
Zamfara	861	915	77	54	6.3

* Lake Chad refers to Eastern Borno State

neighbouring areas. Here the standard deviation values reached up to 250 mm. For most parts of the country, the standard deviations were between 50 and 100 mm, while the most homogenous area comparing all 18 models was in the north east stretching from Jigawa through Jobe and Borno States.

Discussion

According to the model outputs, utilized suitable areas for White Yam production would slightly increase in Nigeria when changes in average monthly rainfall and temperatures are considered. Suitabilities for white yam would increase in most areas which would indicate that the growing conditions for the crop would get slightly better and from the average rainfall patterns, no negative impact could be expected.

In the mid-altitude areas of Nigeria, conditions for white yam production would improve due to higher temperatures together with stable or slightly increasing rainfall amounts. In the lower areas these increasing temperatures, however, would increase physiological stress on the plants.

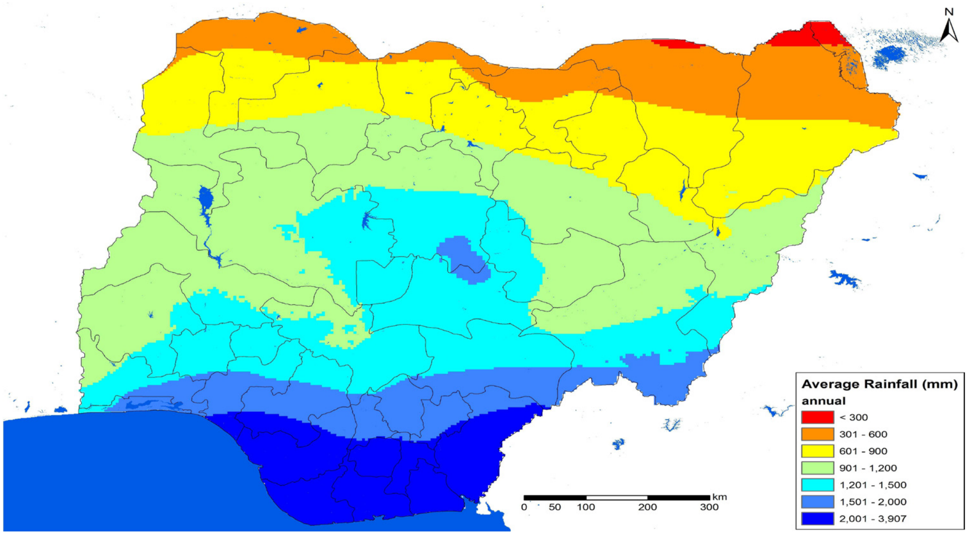

Figure 1. Average annual rainfall (1951-2000)

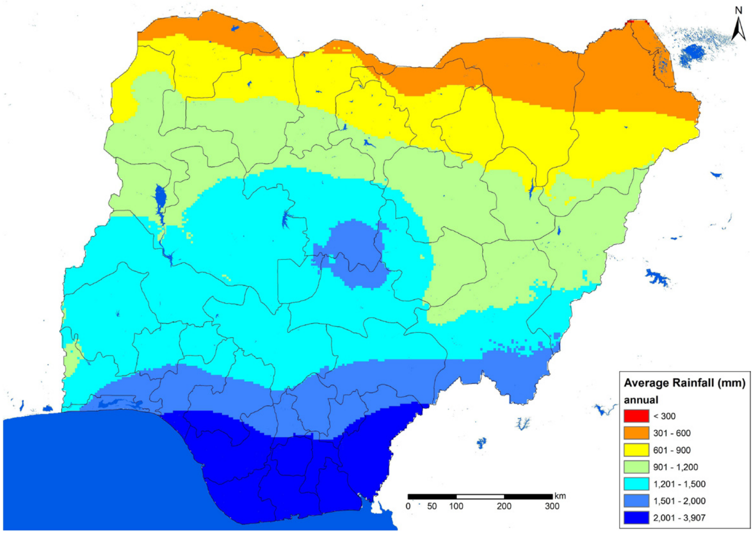

Figure 2. Predicted average annual rainfall (2040-2069) (average of 18 GCM models, a2a scenario)

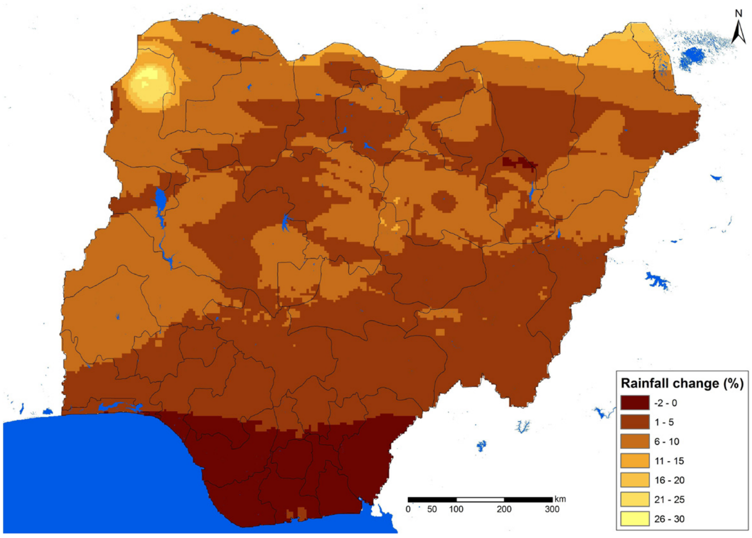

Figure 3. Annual average rainfall change in % period 1951-2000 in comparison with 2040-2069 (average of 18 GCM models, a2a scenario)

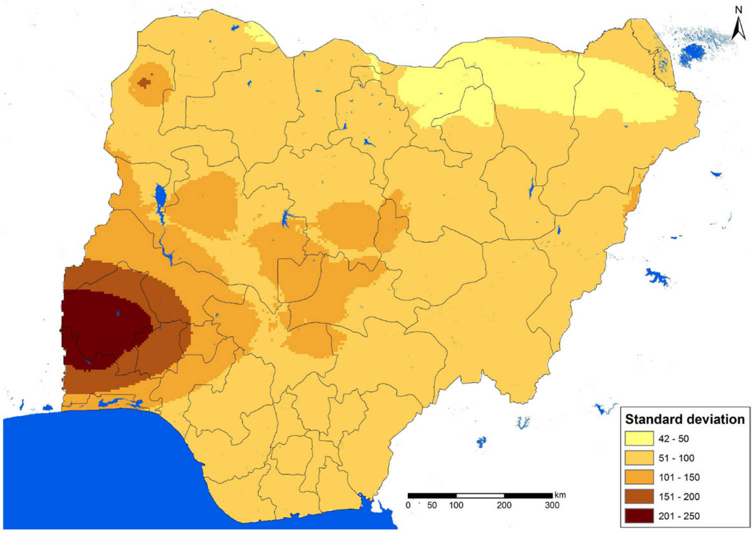

Figure 4. Standard deviations of predicted average annual rainfall (2040-2069) (average of 18 GCM models, a2a scenario)

Additionally the increased concentrations of CO_2 in the atmosphere are expected to have positive effects on crop yields, especially if rainfall is not reduced and temperatures do not rise considerably. In areas of high or mid-latitude, positive effects of rising CO_2 levels are expected to increase yields. (Parry et al., 2004; Parry et al., 2005)

Global climate model outputs vary quite considerably and there are no probabilities attached to any of the models' outputs. The models are validated by using them to predict climate for the past century and if the model outputs describe past climate satisfactorily it is assumed that they would also describe future climate. One way to address these issues is to use a number of models and average them as has been done in this work. In this way, more extreme outputs of drier and wetter models are balanced while standard deviations allow conclusions about how much the model outputs agree.

The model outputs cover only long-term average values and can give no indications about rainfall and temperatures in individual years. According to Boko et al. (2007) it is expected that variability of climate would increase as well as the intensity of precipitation and that growing periods would be reduced.

Conclusions

In order to properly relate impact of changing climate on productivity and yield and the economic and food security implications, a time series of production and yield data and the respective climate data would be needed to derive linear or other relations. For this, ideally on-station yield trials for a number of consecutive years are needed together with meteorological data and the application of identical production parameters. For yam where yield is related to kind and size of planting material utilized, however, this may not fully represent. Alternatively reliable sub-national, e.g., district or LGA level production data for a number of years could be used and related to measured rainfall data for these locations. This would represent an average of production conditions in the field as used by farmers but figures obtained would have to be very reliable. Outputs of crop models could also be utilized if deemed reliable enough to represent reality.

Alternatively crop models could be used in combination with downscaled outputs of CGMs, recent research has utilized EPIC to work on yam (Srivasta, 2010). Further work to integrate yam in common crop modelling packages like DSSAT would be needed.

To get a more complete picture of the uncertainties of climate change predictions, more SRES scenarios outputs should be utilized. It is hoped that a reliable regional climate change model for Africa will be available in the near future as current models work on global scales due to the low density of reliable meteorological stations.

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Changes in iron and moisture contents, pH and peak viscosity of iron-fortified fufu flour during storage in different packaging materials

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Abstract

The need to eradicate nutritional iron deficiency anemia with local diet is important for a successful intervention at the community level in Nigeria. Fufu — a fermented dried wet-sieved mash from cassava major staple food in Nigeria — was fortified with iron sulphate, iron fumarate and sodium iron EDTA at three concentrations (25, 35 and 45 mg/kg). The fortified fufu flour samples were packaged inside high density zip-lock polyethylene bags and plastic jars, and stored at ambient temperatures (28 ± 4 °C) simulating the marketing conditions for fufu in Nigeria. Changes in moisture, iron, pH and peak viscosity of the fortified fufu samples were monitored under storage for 5 months. Samples were analyzed monthly during storage using standard analytical procedures. High density zip-lock polyethylene bags provide a better protective barrier than plastic jars. Moisture content and peak viscosity decreased as storage time increased; pH increased during storage. The iron in fufu stored inside high density zip-lock polyethylene bags was less susceptible to oxidation, and hence, low losses in iron were low after 5 months of storage. NaFeEDTA-fortified fufu samples packed inside zip-lock high density polyethylene bags were more stable during storage than iron sulphate and iron fumarate.

Key words: fufu, iron fortification, storage, changes, chemical composition.

Introduction

Cassava plays a very important role in Nigeria's food security since many Nigerians eat cassava products at least once a day (Ayankunbi et al., 1991). In Nigeria, cassava is traditionally processed before consumption into various products such as gari (roasted fermented granules), fufu (dried fermented starch flour), lafun (dried fermented flour), tapioca (unfermented roasted granules from starch), and pupuru (smoked dried fermented balls) (Nweke, 1994).

Despite its high potentials, cassava and its products are mainly carbohydrate foods (Sanni et al., 1998). Cassava products are major sources of dietary fibers, and so, have some laxative effects, thereby protecting the lower sections of the gastro-intestinal tract against cancers of the colon and rectum (Sanni, 2008). Cassava is very deficient in protein and micronutrients such as irons, calcium, phosphorus, and in vitamins C, A, thiamine, riboflavin and niacin.

Cassava fortification in Nigeria has been dominated by the enrichment of local staple foods (such as gari, lafun and fufu) with soybean protein (Oyewole and Aibor, 1992; Oyewole and Asagbra, 2003). This was aimed at solving protein malnutrition in children, pregnant women, lactating mothers, the aged and the sick (Sanni et al., 2010). Micronutrient fortification of cassava products has been reported (Sanni, 2008; Sanni et al., 2010). Specifically, cassava products fortified with iron (Sodium Iron EDTA, Fe fumarate and Fe sulphate) have been reported to be nutritionally, and economically viable (Sanni et al., 2010). Minerals are more resistant to losses from manufacturing processes and storage than vitamins. However, they do undergo changes when exposed to heat, air, or light, especially during storage. Also, during the storage and processing of food products, added ferrous sources are susceptible to oxidation. This is influenced by the food matrix (pH is an important factor) and storage condition. This paper investigates the effects of storage conditions on the moisture and Fe contents, pH and peak viscosity of iron-fortified and unfortified fufu flour.

Materials and methods

Cassava roots: Cassava roots (TMS 30572, low cyanogen variety) used for this study were obtained from the research farm of the University of Agriculture, Abeokuta, Nigeria. The plants were 12 months old at the time of harvest. The cassava roots were processed within 60 minutes after harvest.

Food grade Iron fortificants: Iron (II) Sulfate heptahydrate (EINECS 231-753-5, Lancaster), Iron (II) fumarate (EINECS 205-447-7, Lancaster, UK) and Ethylenediaminetetraacetic acid iron (III) sodium salt (NaFeEDTA, E6760-500G, Sigma, UK) used in this study were obtained from the United Kingdom.

Production of *fufu* flour. Fufu flour was produced by the traditional method described by Sanni et al. (2003) at the Pilot Plant of the Cassava EU/SME Project, University of Agriculture, Abeokuta. Freshly harvested cassava roots were peeled manually with a stainless steel knife and the woody tips were removed. The peeled roots were washed thoroughly with potable water to remove all dirt and adhering sand particles, cut into chunks of about 15 cm long using a stainless steel knife and steeped in water in a plastic bowl for 5 days at room temperature (30±2°C). After 5 days, the roots were sufficiently soft and were taken out and broken by hand. The fibers were removed by manual sieving: the mash was washed through a muslin cloth sieve. Sieved mash samples were allowed to sediment for 24 hours in a large plastic bowl. After sedimentation, the water was decanted and the sediment was again washed with water. The sediment (fufu paste) was dewatered by being put it into hessian sacks, and pressed with a hydraulic press. The pressed mash was dried in a cabinet dryer at 65°C for 8 hr and then milled into flour using a stainless steel hammer mill.

Fortification of *fufu* flour. A Kenwood mixer (Model FP 505, Kenwood, Britain, UK) was used to mix the three different types of fortificants (Iron sulfate, Iron fumarate and Sodium Iron EDTA) with the fufu flour at 25, 35 and 45 mg of fortificants to 1 kg of fufu flour for 5 minutes (Philar, 2001).

Storage Studies. Iron fortified and unfortified cassava fufu were divided into 1 kg lots and packed into zip-lock high density polyethylene bags (poly bags) and plastic jars. Packaged samples were then stored at ambient temperature (28 ± 2°C) representing the marketing situation in south west Nigeria (Sanni et al., 1998). Stored samples were assessed for iron, moisture, pH and pasting properties (at Crop Utilization Laboratory, IITA, Ibadan, Nigeria) every month throughout the 5 months of storage (Parrish et al., 1980). Moisture content and pH of the samples was determined using AOAC (2001) method. Iron contents were determined using Inductively-Coupled-Plasma-Emission-Spectroscopy-(ICP-ES) as described by Zarcinas et al. (1987). The method described by Sanni et al. (2003) was used to determine peak viscosity using a Rapid Visco Analyser (RVA), (model RVA 3D+, Network Scientific, Australia). All analyses were done in triplicate.

Statistical Analysis. Data obtained were subjected to analysis of variance [ANOVA] and means were separated with Duncan Multiple Range Test (DMRT) (Larmond, 1977) with a statistical significant of $P < 0.05$ using SPSS [Version 10.2, 2002] statistical package.

Results and Discussion

There were changes in moisture content of Iron-fortified fufu flour during storage in different packaging materials for 5 months under ambient conditions (30±2°C) (Fig. 1). Unfortified fufu flour samples in plastic jars had an initial moisture content of 9.12%. This increased to 12.88% after month 5. Iron content increased over the storage period in fortified fufu flour stored in poly bags, as follows: with Fe fumerate from 8.94–9.37% to 12.30–13.42% with Fe sulphate from 8.58–9.11% to 12.31–12.90% and with NaFeEDTA from 8.82–8.91% to 12.65–13.06%. Unfortified fufu flour stored in poly bags, increased moisture content from 9.12% in month 1 to 12.37% in month 5. Iron content increased over the storage period in fortified fufu flour stored in poly bags as follows: with Fe fumerate from 8.94–9.37% to 11.91–12.49% with Fe sulphate from 8.58–8.91% to 11.88 to 12.45% and with NaFeEDTA from 8.82–9.09% to 11.86–12.92%

Cassava products including (fufu) are assumed to be hygroscopic in nature (Igbeka, 1987) and would be expected to gain or lose moisture depending on the relative humidity of the environment and barrier properties of the packaging materials. This would make flour susceptible to deteriorative biological and chemical changes during storage, handling and marketing (Sanni *et al*., 1998). The stability of *fufu* during storage depends greatly on the initial moisture content of the products, storage condition (humidity)

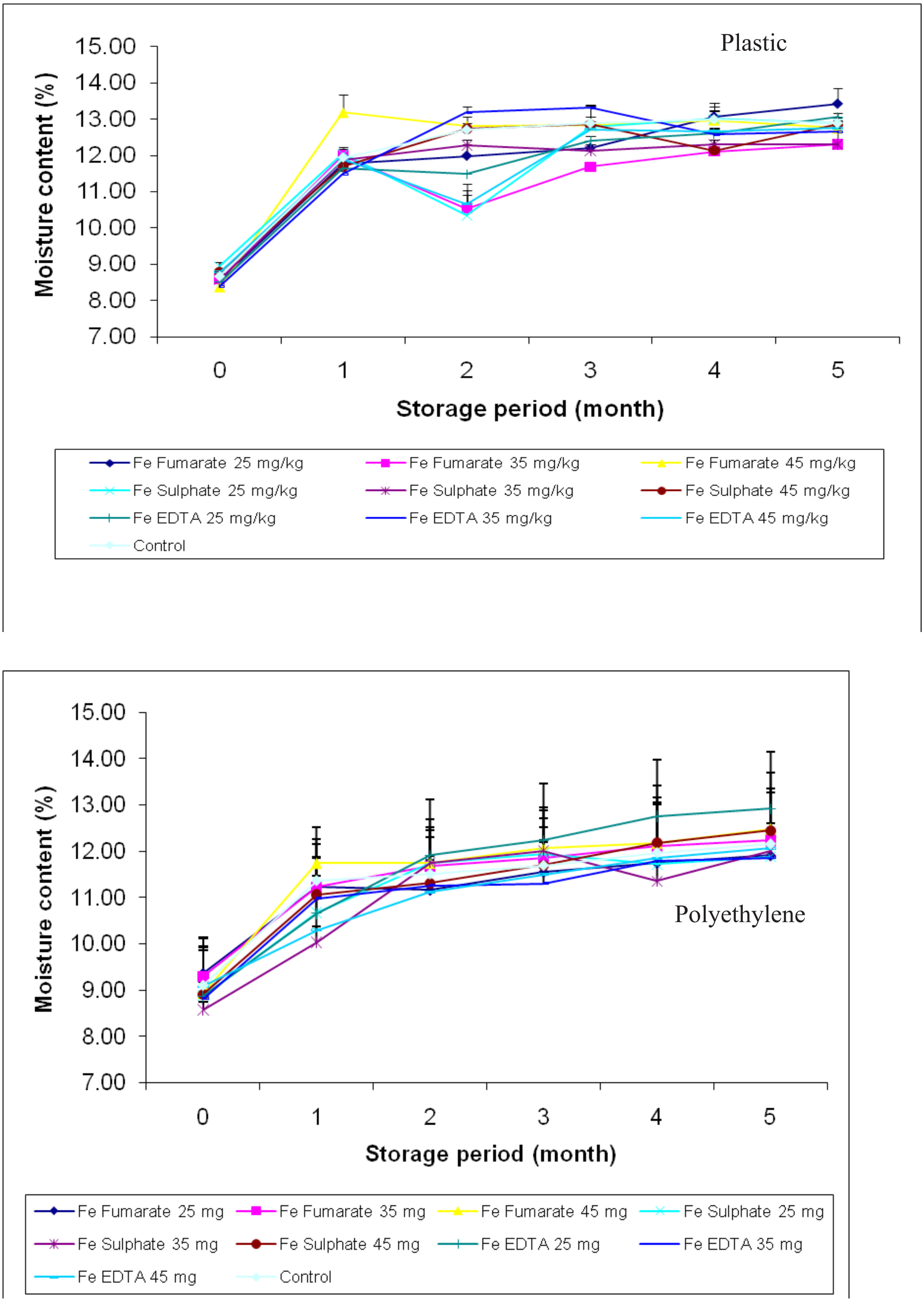

Figure 1: Changes in moisture content of Iron-fortified fufu flour during storage in different packaging materials

and packaging material (Igbeka, 1987; Sanni *et al.*, 1998). The lower the initial moisture content of a product to be stored the better the storage stability of the product. With moisture contents above 15% stored foods easily spoil (Shittu *et al.*, 2001). The role of the weather condition on the stored product shows that the lower the humidity of the storage area the lower the tendency of stored product to absorb moisture and vice versa (Igbeka, 1987; Shittu *et al.*, 2001). High moisture content will expose the flour to insect attack, mold, and bacteria.

Figure 2 presents changes in Fe content of Iron-fortified *fufu* flour during 5 months storage in different packaging materials under ambient conditions (30±2°C). Unfortified *fufu* flour sample stored in polyethylene bag had an initial iron content of 11.39 mg/kg before storage that increased up to the second month of storage and decreased to 9.23 mg/kg after month 5. The iron content in fortified *fufu* flour stored in plastic jars was as follows: for Fe fumerate 11.52–15.06% mg/kg for Fe sulphate 11.62–15.72% mg/kg and for NaFeEDTA 12.89–16.04 mg/kg and increased by month 2 then decereased by month 5 as follows: for Fe fumerate 9.85–12.91 mg/kg, for Fe sulphate 9.26–12.27 mg/kg and to NaFe 9.24–9.73 mg/kg. Unfortified *fufu* flour stored in poly bag, had an initial value of 11.39 mg/kg that increased in the two months of storage and thereafter reduced to 9.13 mg/kg by month 5. The initial iron content of fortified *fufu* flour

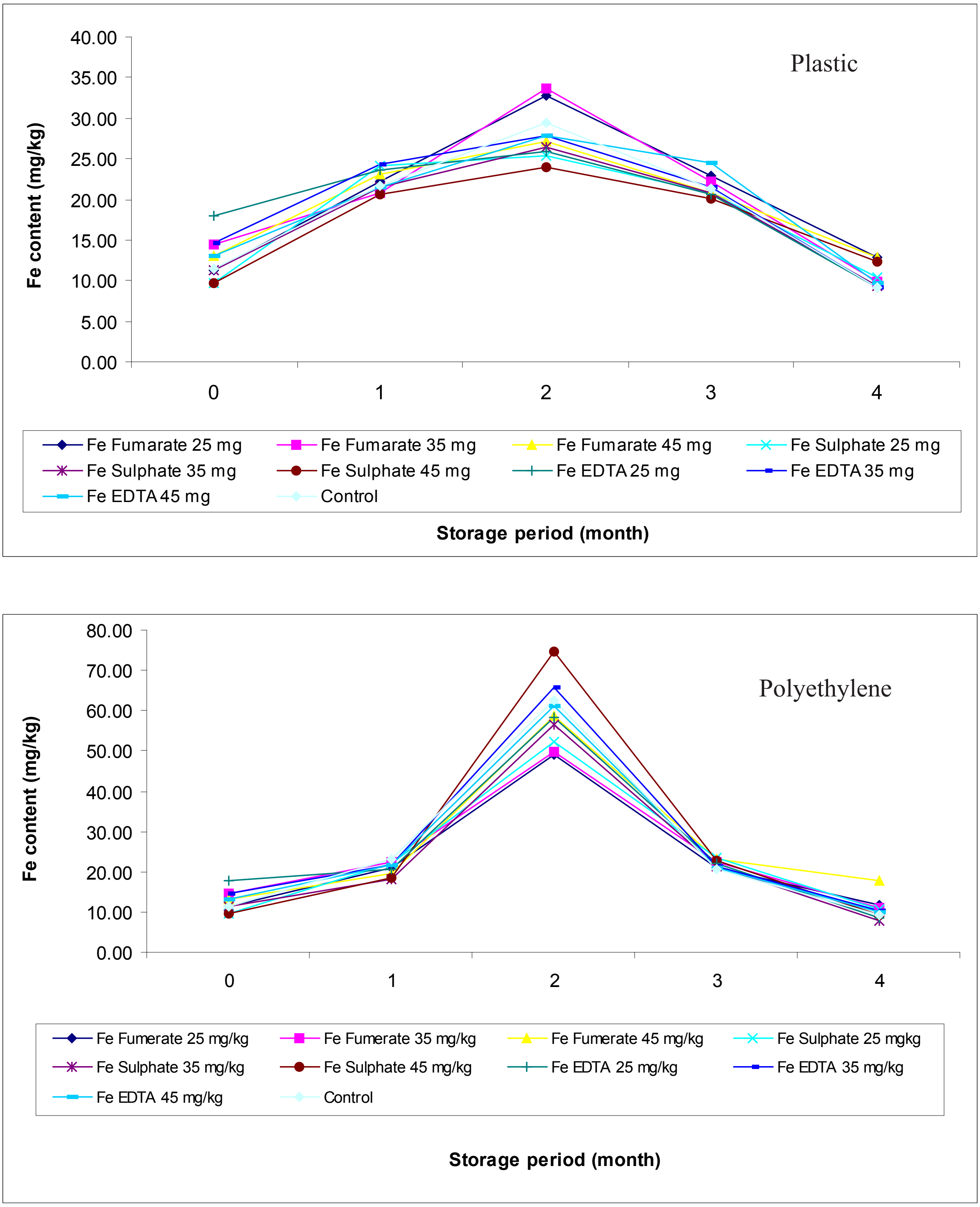

Figure 2: Changes in iron content of Iron-fortified fufu flour during storage in different packaging materials

stored in poly bags was 11.39 mg/kg and decreased to 11.13–17.87 mg/kg (Fe fumerate) 7.91–10.69 mg/kg (Fe sulphate) and 8.59–10.44 mg/kg (NaFeEDTA).

The higher iron content recorded in *fufu* samples packaged in poly bags at the end of storage period showed higher barrier properties than those packaged in plastic jars. Martınez-Navarrete *et al.* (2002) reported that ferrous oxidation increases at a higher moisture level and during oxidation the ferrous form (Fe^{2+}) is converted into the ferric form (Fe^{3+}). Packaging material with an adequate moisture barrier may retain more iron content in fortified samples over a storage period (Nestel, 1993). Lacera *et al.* (1983) had reported satisfactory storage stability using double polyethylene bags with an outer paper layer for instant cereals, and stored in a cool, dry place. Thus moisture proof packaging materials cool and dry storage environment are needed for iron fortified *fufu* flour. Changes in the iron content of fortified *fufu* flour after storage might be due to the oxidation of iron as a result of moisture absorption from the surrounding environment(Martinez-Navarrete *et al.* (2002)

The observed low changes in iron contents during storage for NaFeEDTA fortified cassava products is in agreement with a previous report that the Iron-EDTA complex is relatively stable under most storage conditions (INACG, 2002). Sodium EDTA has been reported to be an accepted food additive that is stable during storage and food preparation (Lynch *et al*., 1993; INACG, 2002). In a study of iron fortification of infant cereals, Hurrell *et al*. (1989) proposed the use of ferrous fumarate and ferrous succinate as they produce no objectionable flavours, odours or colours on storage. According to Bauernfeind (1991a,b), an acceptable iron fortificant for a powdery product is one which does not discolour the salt nor impart a flavour or odour and remains stable and bio-available on storage.

Alleen and Gillespies (2001) have shown that when iron fortificants are added to refined cereals, iron salts such as ferrous sulphate and fumarate are reasonably well absorbed and are suitable. However, the most suitable forms of iron cause oxidation the rancidity of fats and colour changes in food over time. To increase the shelf-life of food products, reduced iron is preferred, but this will not be well absorbed unless the size of the particles is very small (Alleen and Gillespies, 2001). Hence, NaFeEDTA has the potential to be a widely used iron fortificant in *fufu* flour. Ratana *et al*. (2006) showed that ferrous fumarate and ferrous bisglycinate immediately caused precipitation in all types of pasteurized soy sauce stored in a corrugated kraft paper case at room temperature (day time, 25-32^{o}C, night time, 25^{o}C). Over 15 days, the naturally fermented soy sauce fortified with NaFeEDTA was more stable than soy sauce fortified with ferrous fumarate and ferrous bisglycinate.

Figure 3 presents the changes in pH of Iron-fortified *fufu* flour during storage in different packaging materials for 4 months under ambient conditions (30±2^{o}C). Unfortified *fufu* flour sample stored in plastic jar had initial pH of 3.93 before storage that decreased and later increased up to 4.34 after the fifth month of storage. The pH in iron-fortified *fufu* flour stored in plastic jars increased as follows: by month 4 for Fe fumerate from 3.92–3.98 to 4.43–4.45 for Fe sulphate from 3.95–4.02 to 4.33–4.46 and for NaFeEDTA from 3.94–3.95 to 4.37–4.42. As for unfortified *fufu* flour stored in polyethene bag, the initial pH value of 3.92, decreased after first month of storage and then increased up to 4.40 by the fifth month of storage. The pH of iron fortified *fufu* flour stored in poly bags decreased after month 1 but later increased as follows: with Fe fumerate from 3.93–3.96 to 4.54 with Fe sulphate from 3.92–4.06 to 4.30–4.54 with NaFeEDTA from 3.91–3.97 to 4.39. pH is an important factor in the oxidation of iron during storage. The pH of iron fortified *fufu* increased during storage both in samples stored inside poly bags and in plastic jar. This might be due to oxidation of iron as a result of increased moisture content (Martınez-Navarrete *et. al.* 2002).

Figure 4 shows the changes in peak viscosity of Iron-fortified *fufu* flour during storage in different packaging materials for 5 months under ambient conditions (30±2^{o}C). Unfortified samples stored in plastic jars had an initial peak viscosity of 305 RVU before storage, thus decreased up to month 3 and later increased up to 285 RVU after month 5 of storage. In iron fortified *fufu* flour stored in plastic jar,initial peak viscosities decreased and later increased up to month 5 as follows: with Fe fumerate from 298–305 to 275–289 RVU with Fe sulphate from 291–293 to 281–284 RVU with NaFeEDTA from 290–309 to 275–284 RVU. As for unfortified *fufu* flour stored in polyethylene bag, the initial peak viscosity of 305 RVU, decreased after first month of storage and then increased up to 290 RVU by the fourth month of storage. In iron fortified *fufu* flour stored in poly bags, initial peak viscosities decreased after month 1 and 3 then increased up to month 5 as follows: with Fe fumerate from 298–305 to 281–286 RVU with Fe sulphate from 291–293 to 275–299 RVU with

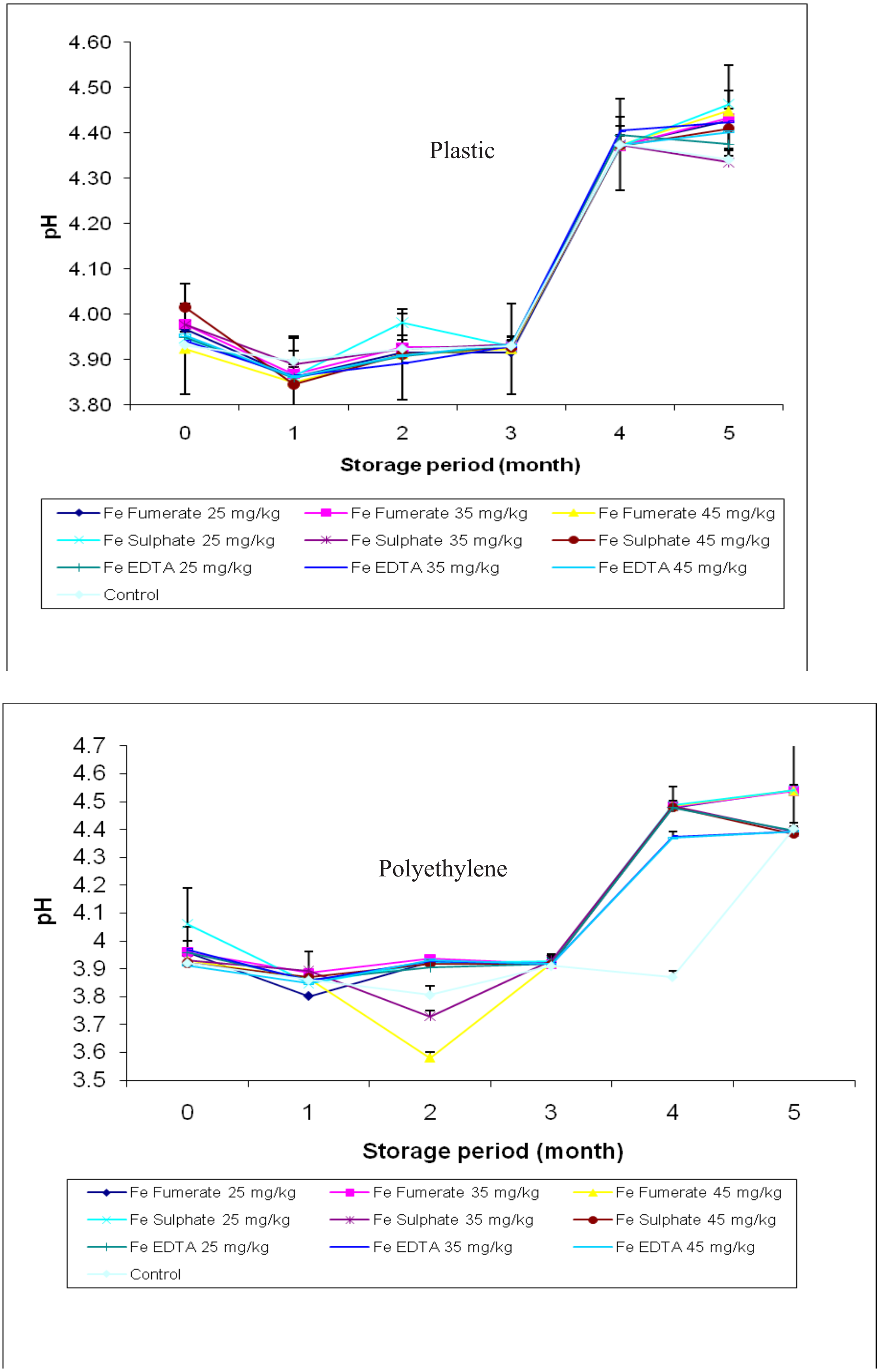

Figure 3. Changes in pH of Iron-fortified fufu flour during storage in different packaging materials

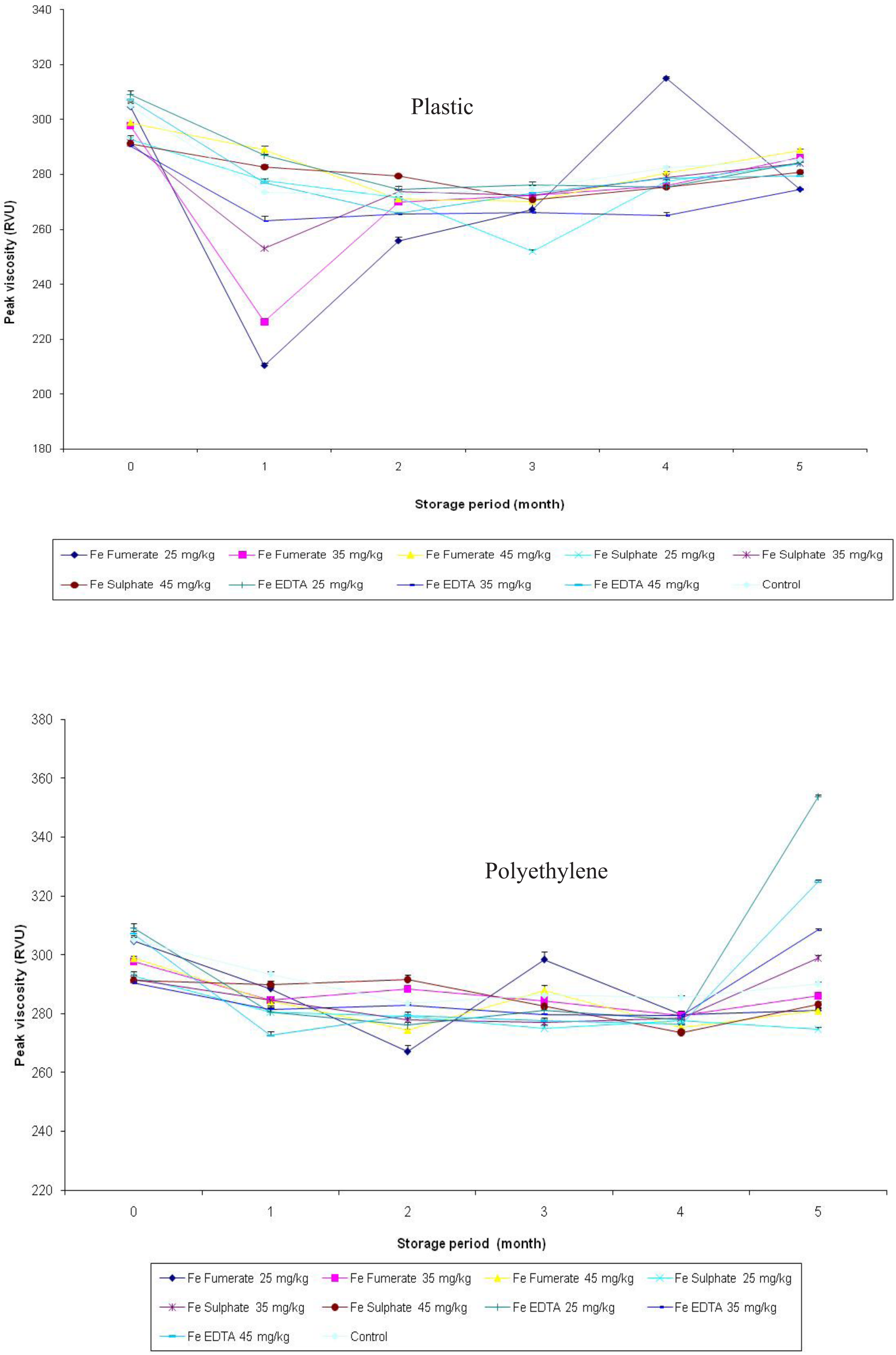

Figure 4: Changes in peak viscosity of Iron-fortified fufu flour during storage in different packaging materials

NaFeEDTA from 290–309 to 308–354 RVU.

The most common form of *fufu* consumption is in the form of cookedstiff paste; hence, its pasting properties are important in predicting the behaviour of iron fortified *fufu* after cooking. The addition of iron fortificants has been reported to reduce the peak viscosities of maize flour (Sanni *et al*. 2008b). Peak viscosity indicates the water-binding capacity of the starch-based products. It is often correlated with the final product quality, and also provides an indication of the viscous load likely to be encountered during mixing and cooking. In this study, peak viscosity decreased as storage time increased. However, changes in the peak viscosity of iron fortified *fufu* are relatively insignificant in both forms of packaging used.

Conclusion

The changes in moisture, pH iron and peak viscosity of iron fortified *fufu* stored in different packaging materials under ambient condition (30±2°C) were presented. Poly bags showed a better protective barrier than plastic jars. NaFeEDTA fortified *fufu* samples packed inside poly bags were the most stable during storage.

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