EFFECTS OF MICROBIAL FERMENTATION ON THE PROXIMATE, MINERAL AND ANTINUTRITIONAL CONSTITUENTS OF SELECTED VARIETIES OF CASSAVA PRODUCTS

BY

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DECLARATION

I declare that the work in this Dissertation entitled 'Effects of Microbial Fermentation on the Proximate, Mineral and Antinutritional Constituents of Selected Varieties of Cassava Products' has been carried out by me in the Department of Chemistry under the supervision of my supervisors. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another degree or diploma at this or any other university.

Muhammad Etsuyankpa Binin

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Name of Student	Signature	Date

CERTIFICATION

This dissertation entitled 'EFFECTS OF MICROBIAL FERMENTATION ON THE PROXIMATE, MINERAL AND ANTINUTRITIONAL CONSTITUENTS OF SELECTED VARIETIES OF CASSAVA PRODUCTS' by Etsuyankpa Binin MUHAMMAD meets the regulations governing the award of the degree of Doctor of Philosophy of the Ahamadu Bello University, Zaria, and is approved for its contributions to knowledge and literary presentation.

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ABSTRACT

To investigate the effects of fermentation on the proximate, mineral and anti-nutrient compositions of some cassava products, the pulps of 9 varieties of cassava were fermented with pure strains of *Saccharomyces cerevisae* and *Lactobacillus bulgaricus* for three days; these were subsequently processed into 'fufu' and 'gari'. Similarly, the pulps were also chance fermented without microbial inoculation and made into another set of 'gari' and 'fufu' while some were made directly into 'lafun' without fermentation to allow for comparative studies. Some of the varieties of cassava tubers were collected from Niger State Agricultural Development Project, Minna, Nigeria, while some were sourced from farmers within the areas
under investigations. These tubers were washed, peeled, grated prior to aseptic inoculation with the organisms in liquid nutrient broth. The fermented mash was subsequently dried, pulverised and processed traditionally to 'gari' and 'fufu' while the dried cassava tubers were milled into 'lafun' flours. The physico-chemical compositions of the soil samples where these cassava tubers were planted were also invetigated.The results of the study revealed that microbial fermentation caused significant ($p < 0.05$) increase in the protein (9I%) and fat (98%) contents and decreased fibre (85%) and carbohydrate (10%) compositions. There were also significant reductions of cyanide, tannins, saponins, phytate and oxalate contents. Conversely, microbial fermentation of the cassava caused increase in Zn, Mg, Ca, Na, K, P and Fe contents, whose values were found to be higher than those of the soil samples. The results of this study suggest that cassava products can be nutritionally improved with *S. cerevisiae* and *Lactobacillus bulgaricus* fermentations.

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GLOSSARY

TME419 = Improved variety of a cassava
SITME419 = *S. cerevisea* fermented
KG = Karimugi variety
LITME419 = *L. bulgaricus* fermented
LIKG = *L. bulgaricus* fermented
LITMS92/0326 = *L. bulgaricus* fermented
SITMS92/0326 = *S. cerevisea* fermented
SIKG = *S. cerevisea* fermented
TMS92/0326 = Improved variety of a cassava
BI = Baba Iya variety
LIBI = *L. bulgaricus* fermented
SIBI = *S. cerevisea* fermented
W = Wahabi variety
LIW = *L. bulgaricus* fermented
SIW= *S. cerevisea* fermented
B = Kpace Bokun variety
LIKB = *L. bulgaricus* fermented
SIKB = *S. cerevisea* fermented
KD = Kpace Dzuru variety
LIKD = *L. bulgaricus* fermented
SIKD = *S. cerevisea* fermented
DW = Dan Warri variety
LIL30572 = *L. bulgaricus* fermented
LIDW = *L. bulgaricus* fermented
SIDW = *S. cerevisea* fermented
L30572 = Improved vaiety of cassava
SIL30572 = *S. cerevisea* fermented
AP = Available phosphorus
TC = Textural class
OC = Organic carbon
OM = Organic matter
SL = Sandy-loam
LS = Loamy-sand
SPGSS = Shipagbe Subsoil
SPGTS = Shipagbe Topsoil
KSOSS = Kpasson Subsoil,KSOTS = Kpasson Topsoil
GWMSS = Gwam Subsoil
GWMTS = Gwam Topsoil
JTATS = Jita Topsoil
JTASS = Jita Subsoil KWOTS = Kawo Topsoil
KWOSS = Kawo Subsoil,
WSSSS = Wushishi Subsoil
WSSTS = Wushishi Top soil
MATTS = Maito Topsoil

MATSS = Maito Subsoil
BNGSS = Bunigi Subsoil
BNGTS = Bunigi Topsoil
KPFSS =Kupafu Subsoil
KPFTS = Kupafu Top soil
KCTTS = Kuchita Topsoil
KCTSS = Kuchita Subsoil
BTVTS = Batavovogi Topsoil
BTVSS = Batavovogi Subsoil
BNGSS = Bunigi Subsiol
BNGTS = Bunigi Topsoil

CHAPTER 1

INTRODUCTION

1.1 Background to the Study

Among the world's staple crops, cassava has the lowest protein/energy ratio (7.4 mg protein/cal compared to 26 mg protein/cal for maize) and is deficient in iron, zinc, pro-vitamin A or β-carotene and vitamin E. This is coupled with the fact that it has one major problem; the roots and leaves of poorly processed cassava plants contain a substance that, when eaten, can trigger the production of cyanide.This is a serious problem for the 500 million people who rely on cassava as their main source of calories, among them are subsistence farmers in Sub-Saharan Africa (Richard, 2011; Sayre, 2003).

Proteinous foods are usually known to be expensive and beyond the reach of most of the populace. Its scarcity has greater impact on children, whose physical and mental development require nutritionally balanced diets. Malnutrition leads to stunting and underweight (Hahn, 1992). The utilisation of cassava is limited by its extremely low protein content and so the consumption of its products has been implicated in malnutrition. Low protein intake in Africa has been attributed to the increasing high cost of traditional sources of animal protein (Akoja and Mohammed, 2011).

In many regions of the world over 30% of the population have insufficient calories in their diet to meet their nutritional needs. By 2020, the Food and Agricultural Organisation (FAO) has estimated that one billion persons will be undernourished or receive insufficient calories in their diet. No where is this problem more severe than in sub-Saharan Africa. In addition to receiving insufficient calories in the diet, many subsistence farmers depend on a single staple crop for most of their calories. Some of these staple crops may not provide a balanced or complete supply of

micronutrients and vitamins, leading to malnutrition. Globally, vitamin and mineral deficiency affect one third of all people. One mechanism to quantify the impact of malnutrition on human population is the Disability Adjusted Life Years or DALY. A DALY is the sum of the years of life lost due to preventable death and years lost due to disability or disease. Among the micronutrient deficiencies, vitamin A, iron, zinc, and iodine deficiencies affect most persons globally, resulting in the loss of over 53 million DALYs per year. Sub-Saharan Africa's share of this total is 55% (Richard, 2011).

Cassava consumption is not equally distributed throughout Africa. The largest per capita consumers are largely in West Africa and include Nigeria, the Democratic Republic of Congo and Ghana (Richard, 2011). Cassava is to African peasant farmers as rice is to Asian farmers, or wheat and potatoes are to European farmers (Montagnac *et al.*, 2009).

Cassava plays a food security role in areas prone to drought, famine and in periods of strives and civil disturbance. The crop's ability to provide a staple food base is a function of its flexibility in terms of planting and harvesting strategies, and because of its relative tolerance of poor soils and pest/disease problems. This explains why it is valued in Africa in part, for the food security it provides (Akoja and Mohammed, 2011; Richard, 2011) In addition, the roots typically have a 20-fold lower cyanogen content than leaves. The so-called sweet (low cyanogens) varieties may be consumed directly with little processing but high cyanogen (bitter) varieties must be extensively processed to remove the cyanogens prior to consumption (Richard, 2011).

Cyanogens are found in 3 forms in cassava: cyanogenic glucoside (95% linamarin and 5% lotaustratin), cyanohydrins, and free cyanide. These glucosides, typified by linamarin [alpha-Hydroxyisobutyronitrile-beta-D-glucose] or [2-(beta-D-Glucopyranosyloxy)-2-

methylpropanenitrile] (molecular formula: $C_{10}H_{17}NO_6$) and lotaustralin [2-(beta-d-glucopyranosyloxy)-2-methylbutyronitrile] or [2-(-D-Glucopyranosyloxy)-2-methylbutyronitrile] (moleular formular: $C_{11}H_{19}NO_6$) are hydrolysed to hydrocyanic acid (HCN) by endogenous linamarase (beta-glucosidase or β-glucosidase) when cassava tissues are disrupted by cutting, grating, bruising or other mechanical means. Different processing techniques exist to remove cyanogens and their effectiveness depend on the processing steps and the sequence utilized, and it is often time-dependent (Montagnac *et al.,* 2009; Ayodeji *et al.,* 2005; Giraud *et al*., 1992).

Cyanide is found to be the most toxic factor restricting the consumption of cassava roots and leaves. Indeed, cassava, particularly its bitter varieties, has a cyanide level higher than the Food and Agricultural Organisation/World Health Organisation (FAO/WHO) (1991) recommendations, which is < 10 mg cyanide equivalents/kg DM, to prevent acute toxicity in humans. Cassava leaves have a cyanide content ranging from 53 to 1,300 mg cyanide equivalents/kg of Dry Matter (DM), and cassava root parenchyma has a range of 10 to 500 mg cyanide equivalents/kg DM; both of these are much higher than what is recommended.

Phytate (inositol hexakisphosphate) is another compound found in high abundance in cassava, with approximately 624 mg/100 g in roots. Phytic acid is able to bind cations such as magnesium, calcium, iron, zinc, and molybdenum and can, therefore, interfere with mineral absorption and utilization which may affect requirements. It may also bind proteins preventing their complete enzymatic digestion (Norhaizan *et al*., 2009; Sarkiyayi and Agar, 2010).

The polyphenol content (tannins) in cassava leaves is increased with the maturity of the plant. Cassava leaf meal has a polyphenol content of 2.1 to 120 mg/100 g DM. Polyphenols can form insoluble complexes with divalent ions such as iron, zinc, and copper. They can also inactivate

thiamin, bind certain salivary and digestive enzymes, and enhance secretion of endogenous protein. Consequently, they inhibit nonheme-Fe absorption, reduce thiamin absorption and the digestibility of starch, protein, and lipids, and also interfere with protein digestibility(Adeniji *et al*., 2007).

Oxalates are antinutrients affecting calcium and magnesium bioavailability and form complexes with proteins, which inhibit peptic digestion. Oxalate content ranges from 1.35 to 2.88 g/100 g DM for cassava leaf meal. The negative effect of oxalates on humans depends on the level of both oxalate and calcium in the cassava leaves (Holmes and Kennedy, 2000; Tracy, 2007).

Saponins are plant glycosides that are studied for their potential health benefits, particularly those derived from ginseng and soy. Saponins are considered the bioactive component of ginseng responsible for its metabolic and potential health effects. Saponins can also act on the central nervous system of humans with potential therapeutic effects. Cassava leaf meal has a steroidal saponin content ranging from 1.74 to 4.73 g/100 g DM, which compares to those found for soybeans (0.07 to 5.1 g/100 g DM), but is lower than those observed in alfalfa (5.6 g/100 g DM) and beet leaves (5.8 g/100 g DM). Saponin content increases in cassava leaf meal with plant maturity. Cassava leaf meal has a trypsin inhibitor content of 3.79 inhibited trypsin unit (ITU)/mg DM at the starch accumulation phase (17-mo-old plant) and of 11.14 ITU/mg DM at the leaf development phase (12-month-old plant). Trypsin inhibitor has adverse effects on the pancreas (Montagnac *et al.*, 2009).

For the full nutritional potentials of cassava roots and leaves to be realized, research efforts must intensified more on the development of simple, low-cost but efficient techniques that would rid them of cyanide as well as other anti - quality constituents such as tannin and phytin.

Of the series of available cassava processing methods, fermentation is the first major step in the production of products of cassav such as 'gari', 'fufu' and 'lafun'. The reasons for fermentation of the cassava products mentioned are synonymous with the reasons canvassed generally for embarking on fermentation, which include among others: biological enrichment of the substrate in terms of protein, vitamins, essential amino acids and essential fatty acids; detoxification of food anti-nutrients during the process of fermentation; impartation of good aroma, flavour and texture; preservation of the fermented products and decrease in cooking time and fuel requirement (Aro, 2008). Fermentation has been identified as one of the less expensive means of increasing the protein quality of cassava (Andrew And Peter, 1980; Aro, 2008).

In the modern proceessing techniques, fermentation of cassava pulp has been enhanced by the addition of non-pathogenic microorganisms during fermentation. The use of microorganisms to convert crbohydrates, lignocellulose and other industrial wastes into foodstuffs rich in protein is possible due to the following characteristics (Aro, 2008).

Firstly, microorganisms have a very fast growth rate.Their protein cotents is quite high varying from 35 to 60%, the nutritional values are as good as other conventional foods rich in protein (Kobawila *et al*. 2005). Microorganisms also have the ability to produce an amount of essential nutrient(s) sufficient to correct or prevent the deficiency when the food is consumed in normal amounts by the population at risk. Also, the nutrient(s) produced by the organisms do not impart undesirable characteristics to the food (changes in colour, taste, smell, texture, or cooking properties) and do not unduly shorten the shelf life. The use of microorganisms on food also give reasonably low additional cost to the consumer, resulting from the microbial protein formation.

Moreso, animals need certain amino acids, which their cells cannot synthesise, "indispensable amino acids". Fermentative microbes can synthesise and provide these. They can synthesise protein from non-protein nitrogen sources; fermentative microbes can, for example, utilise urea to synthesise protein (Ahaotu *et al*., 2011).

In Africa, improperly processed cassava is a major problem. It is associated with a number of cyanide-related health disorders, particularly among people who are already malnourished. It is mostly women and children who are susceptible to cyanide poisoning.Women are usually charged with processing the plant, which leaves them susceptible to inhaling cyanide gas. Cyanide can poison a person by either inhalation or ingestion (Jack *et al*., 2002).

The composition of cassava depends on the specific tissue (root or leaf) and on several factors, such as geographic location, variety, age of the plant, and environmental conditions (Montagnac *et al*., 2009).

1.2 The Need For Fermentation of Cassava

Fermentation of cassava results to its products being fermented foodstuffs, which according to Etudaiye *et al*. (2009) and Emmanuel *et al*. (2010) are defined as animal or plant tissues subjected to the action of microorganisms and/enzymes to give desirable biochemical changes and significant modification of the food quality. The general reasons advanced for such fermentation as outlined by these authors are :

Detoxification of food/feed anti-nutrients during the process of fermentation reults. Also there is occurance of a biological enrichment of food substrates with proteins, minerals, essential amino acids, essential fatty acids and vitamins. Enrichment of the fermented products through the

impartation of an array of aroma, flavours and textures as well as the preservation of the fermented products through the production of lactic acid, acetic acid, alcohol and alkali in the substrate as a result of fermentation are essentially achieved.

1.3 Microorganisms Used for the Fermentation of Cassava

Saccharomyces cerevisiae, one the microorganisms used in the fermentation of cassava pulp, is an eukaryotic microbe, yellow-green yeast belonging to the fungi kingdom, which includes multicellular organisms such as mushrooms and molds. Natural strains of the yeast have been found on the surfaces of plants, the gastrointestinal tracts and body surfaces of insects and warm-blooded animals, soils from all regions of the world and even in aquatic environments. Most often it is found in areas where fermentation can occur, such as the one on the surface of fruit, storage cellars and on equipment used during the fermentation process.

S. cerevisiae is famously known for its role in food production. It is the critical component in the fermentation process that converts sugar into alcohol, an ingredient shared in beer, wine and distilled beverages. It is also used in the baking process as a leavening agent; the release of gas by yeast into their environment results in the spongy-like texture of breads and cakes.

Lactobacillus bulgaricus is a helpful natural bacterium, and a member of the family microflora, that can fight harmful bacteria that may invade ones digestive system. L. bulgaricus is a specific type of micro-organism that is known as a probiotic (Oboh and Elusiyan, 2007; Oboh *et al* 2003).

1.4 Description of Cassava

Cassava (*Manihot esculenta*), also called yuca or manioc, is a woody shrub of the *Euphorbiaceae* (spurge family) native to South America that is extensively cultivated as an annual or perennial

crop in tropical and subtropical regions for its edible starchy tuberous root, it is a major source of carbohydrates, which it produces in 6 months to 3 years after planting. The flour made of the roots is called tapioca (Irtwange and Achimba, 2009; Offor *et al*., 2011)

The name "cassava" is sometimes spelled cassaba or cassada. In English language publications, the plant may be occasionally called by local names, such as mandioca, aipim, macaxeira or ketalla (Brazil); kassav (Haiti); mandi´o (Paraguay); akpu, ugburu, ige, or rogo (Nigeria); bankye (Ghana); mogo or mihogo (Swahili-speaking Africa); kappa, simal tarul or kelala (India); maniok (Sri Lanka); ubi singkong, obikajoe or Kaspï (Indonesia); ubi kayu (Malaysia); kamoteng kahoy, balanghoy or Tentu neskok (Philippines); mushu (China); củsắn or khoaimì (Vietnam); and manioke , tapioka or manioka (Polynesia); bafifanapaka or delhazo (Madagascar); cassave (Netherland.); caxcamotï (Guatemala.); guacamote (Mexico.); kute (agbeli) (Togo); manoco (P. Rico); ramu (Latin America.); yautia, yuca (South America) (Ebuchi *et al*., 2005).

It has latex in all its parts, which produces enlarged tuberous roots. There are over 100 cultivars and there is great variation in the form of the plant. The height ranges from about 1 to 3 m or more. The stems are usually slender and glabrous, with leaves borne near the apex; the lower parts of the stems have nodes made conspicuous by prominent leaf scars. Branching is variable; some cultivars branch near the base and are spreading in form, others are erect and branch nearer the apex. Stems vary in colour, being grey or silvery, green, greenish-yellow, reddish-brown, or streaked with purple. The leaves, which are spirally arranged with phyllotaxis 2/5, have petioles 5-30 cm long, usually longer than the blades; the blades are deeply palmately divided with 5-7 (occasionally 3-9) lobes, each 4-20 cm long and 1-6 cm wide, obovatelanceolate, pointed and

with entire margins. They vary in colour from green to reddish; the petiole and midrib may be deep red. Older leaves are shed leaving the prominent leaf scars mentioned above. The flowers are borne in axillary racemes near the ends of branches, and are monoecious, pale yellow or red, 1-1.5 cm in diameter. The fruit is a six-winged capsule with 3 ellipsoidal seeds each about 12 mm long. Root tubers develop by a process of secondary thickening as swellings on adventitious roots a short distance from the stem (USDA/NRCS, 2003).

Great variation is shown in the number, shape and size of the tubers and the angle at which they penetrate the ground. There are usually 5-10 tubers per plant, cylindrical or tapering, 3-15 cm in diameter and 15-100 cm long, occasionally longer. Hydrocyanic glycoside is present in varying quantity. Cassava root is long and tapered, with a firm homogeneous flesh encased in a detachable rind, about 1 mm thick, rough and brown on the outside. Commercial varieties can be 5 to 10 cm in diameter at the top, and 50 to 80 cm long. A woody cordon runs along the root's axis.The flesh can be chalk-white or yellowish.

Cassava clones are often classified by taste as 'sweet' or 'bitter', but - contrary to the commonly stated notion - this does not always reflect a direct relationship with the cyanogenic glycoside content of the root. The two types have sometimes been regarded as different species, the former being called *M. esculenta* and the latter *M. palmata* or *M. dulcis*. This division is clearly not tenable. Further, the toxicity of a cultivar varies according to environmental growth conditions. However, in any one location it is possible to find some cultivars 'bitter' and some 'sweet', so that a local separation between bitter and sweet are often being made (USDA/NRCS, 2003).

Improper preparation of bitter cassava causes a disease called “konzo”. Nevertheless, it has been shown that farmers often prefer the bitter varieties because they deter pests, animals, and thieves (Delange *et al*., 1994).

Cassava roots are known to be very rich in starch, and contain significant amounts of calcium (50 mg/100g), phosphorus (40 mg/100g) and vitamin C (25 mg/100g). However, they are described as poor in protein and other nutrients. In contrast, cassava leaves are a good source of protein if supplemented with the amino acid methionine despite containing cyanide (Sarkiyayi and Agar , 2010; Offor *et al*., 2011)

1.5 History of the Development of Cassava

Wild populations of *M. esculenta* subspecies *flabellifolia*, shown to be the progenitor of domesticated cassava, are centered in West-central Brazil, where it was likelyto be first domesticated, no more than 10,000 years BC. By 6,600 BC, manioc pollen appears in the Gulf of Mexico lowlands, at the San Andres archaeological site. The oldest direct evidence of cassava cultivation comes from a 1,400 year old Maya site, Joya de Cerén, in El Salvador, although the species *Manihot esculenta* likely originated further in South in Brazil and Paraguay (Adamu, 1989; CGIAR, 1997).

Céline *et al*. (2010) and Bede (1980), pointed out that it was one of the first crops to be domesticated, and there is archaeological evidence that it was grown in Peru 4,000 years ago and in Mexico 2,000 years ago.

According to CGIAR (1997), cassava originated in Central and South America, and it spread rapidly and arrived on the West coast of Africa via the Gulf of Benin and the River Congo at the

end of the sixteenth century, probably in slave ships, and on the East coast via the Reunion Island, Madagascar, and Zanzibar at the end of the eighteenth century. In related literature, Richard (2011) revealed that cassava was brought to Africa in the 16th century from Brazil by Portuguese sailors and rapidly spread throughout the continent. The crop then spread inland from both sides. By the early 1800s cassava arrived in India, but controlled breeding did not begin until the 1920s (CGIAR, 1997; Bede 1980; Montagnac *et al*., 2009). It was widely grown in Africa and South - East Asia by the 1850s (Bede, 1980; Davis *et a.l*, 2009).

Since its introduction into West Africa in the sixteenth century, cassava has spread rapidly to various parts of Africa, where it is grown alone in sequence or in different inter-cropping systems with other staples, cassava is now an important staple in Southern Nigeria, parts of Ghana, Ivory Coast, Sierra Leone, Liberia, Guinea, Senegal, the United Republic of Cameroon, Gabon, Zaire, Central African Republic, Madagascar, Tanzania, Uganda, the Southern Sudan, Angola, Mozambique and Kenya. In countries such as Sierra Leone and Zaire, cassava leaves are popular leaf vegetables (Bede, 1980; Davis *et al*., 2009).

1.6 **Statistics of Cassava Production**

Cassava, a staple crop that takes the 7th rank all over the world, represents an inadequately explored source for nutrition (Echebiri and Edaba, 2008; Odoemenem and Otanwa, 2011). It is known to be the most important root crop in the world and ranks second among African staple crops (Kristen *et al*., 2005). World production of cassava over the last two decades has steadily increased, mainly because of increase in the areas under cultivation. According to Smith (1997), total world production in 1968 was 85.6 million tonnes grown on 9.8 million hectares of land. These figures are probably lower than the actual production figures, because cassava is still

grown largely by subsistence farmers who cultivate small scattered plots which are often missed out during compilation for agricultural statistics. Nevertheless, based on the available figures, the annual world production of cassava is only exceeded by six other crops, mainly wheat, rice, maize, barley, potatoes, and sugar beets (Echebiri and Edaba, 2008; Odoemenem and Otanwa, 2011; Smith, 1997). Two years later, Bede (1980) gave a similar estimate of the annual world production of over 100 million tonnes in 1972.

By 1979, the cultivated area was 13.5 million hectares, with a total production of 123.3 million tonnes. The area cultivated in 1985 increased to 14.2 million hectares, with a total production of 136.5 million tones (Echebiri and Edaba, 2008; Odoemenem and Otanwa, 2011). In addition, a total of 16.8 million hectares was planted with cassava throughout the world in 2000; about 64% of this was in sub-Saharan Africa. The yields in tonnes/hectare for the 3 periods were respectively, 8.7, 9.2 and 9.2 for 1968,1979 and 1985 (Echebiri and Edaba, 2008). The average yield of cassava in 2000 was 10.2 tonnes per hectare, but this varied from 1.8 tones per hectare in Sudan to 27.3 tonnes per hectare in Barbados. In Nigeria, the average yield of the crop was 10.6 tones per hectare (Agwu and Anaeyeche , 2007).

In another stastical evaluation by Ajakaye and Ojo (2009), world production of cassava root was estimated to be 184 million tonnes in 2002. The majority of production is in Africa where 99.1 million tonnes were grown. About 51.5 million tonnes of cassava were grown in Asia and 33.2 million tonnes in Latin America and the Caribbean.

However, based on the statistics from the FAO of the United Nations, Thailand is the largest exporting country of dried cassava with a total of 77% of world export in 2005. The second largest exporting country is Vietnam, with 13.6%, followed by Indonesia (5.8%) and Costa Rica

(2.1%). Worldwide cassava production increased by 12.5% between 1988 and 1990. (Odoemenem and Otanwa, 2011; Offor *et al*., 2011).

According to FAO estimates, 172 million tonnes of cassava was produced worldwide in 2000 (IITA, 2009). Further analysis indicated that 40 per cent of the current world production takes place in Africa. Brazil accounts for 30 million tonnes annually, Zaire 10.5 million, Indonesia 10.5 million and Nigeria 7.5 million tonnes. Other major producing countries that make up the bulk of the world's market supplies of cassava products are Thailand, Madagascar, Indonesia, and Benin. In 1999, Nigeria produced 33 million tonnes making it the world's largest producer (IITA, 2009). Agwu and Anaeyeche (2007) reported that Nigeria was ranked the largest producer of cassava in the world with an annual estimate of 39 million tonnes and that Nigeria's production accounts for 19% of the world's output and 34% of Africa's output. According to Agwu and Ananyaeche (2007), 80% Nigerians in the rural areas eat a cassava meal at least once a week and majority eat cassava at least once a day; hence it plays a major role in the country's food security. The high consumption of cassava in the country led to an increase in the demand for this crop forboth food and industrial uses, which exceeded the supply (Agwu and Ananyaeche, 2007).

To reverse this trend, the International Institute of Tropical Agriculture (IITA) and National Roots Crop Research Institute (NRCRI) in Nigeria led the development of improved cassava cultivars through their breeding programmes to obtain higher quality cassava roots at relatively shorter time and pest/disease resistant cassava cultivars capable of adapting to a wide range of ecological conditions and farming systems (Agwu and Ananyaeche, 2007).

According to Factfish of Food and Agricultural Organisation of United Nations (FAOSTAT), (2010 - 2013), Nigeria produced 52,403,500 tonnes of cassava in 2011, followed by Brazil with the production of 25,441,700 tonnes. Of the top ten countries of the world in the order of production - Nigeria, Brazil, Indonesia, Thailand, Democratic Republic of Congo, Angola, Ghana, Vietnam and India – Nigeria has been taking the lead since 2003 till date.

Among the steady staples, cassava gives a carbohydrate production which is about 40% higher than rice and 25% more than maize, with the result that cassava is cheapest source of calories for both human and animal feeding. Cassava is a staple food for over 200 million Africans. It is estimated that the crop provides about 40% of all the calories consumed in Africa and ranks second only to cereal grains as chief source of energy in Nigerian diet. Cassava roots contain mainly carbohydrates, of which 80% is starch and >1% fat. Cassava is the third largest source of carbohydrates for human food in the world (Etudaiye *et al*., 2009; Offor *et al*., 2011)

In the subtropical region of southern China, cassava is the fifth largest crop in term of production, after rice, sweet potato, sugar cane, and maize. China is also the largest export market for cassava produced in Vietnam and Thailand (Echebiri and Edaba, 2008). It has been shown that the average annual per capita consumption of cassava in 2002 was 287 kg in the Democratic Republic of Congo and 127 kg in Nigeria (Kristen *et al.,* 2005). As a rough estimate, about 10 million tonnes of cassava are processed into gari annually in Nigeria alone (Ganiyu, 2006).

Cassava production, averaged over 24 countries, has increased more than threefold from 1980 to 2005, and the population has more than doubled over that time compared with a 1.5 times increase worldwide (Kirsten *et al.,* 2011; Wanda *et al*., 1998)

1.7 Importance of Cassava

Cassava is not only used in many food preparations for human consumption, but is of importance in industries (starch, textiles, fuel, confectionery etc.), and in animal feeds particularly in nonruminant diets and ruminants (Sokaria .and Kariboa, 1992; Kirsten *et al.,* 2011).

The tubers may be kept in the soil for extended time periods. This secures rural farmers a carbohydrate source in years with adverse growth conditions where other crops fail and famine would otherwise prevail. These features and high crop yield contribute to the importance of cassava in Africa, South East Asia, and South America. Industrial cassava starch production is important, especially in South East Asia. Cassava leaves are not widely used as a food source despite their high protein content (Kristen *et al*., 2005; Kobawila *et al*., 2005)

1.7.1 Human Consumption

Forms in which cassava is consumed as food include, raw cassava, boiled cassava, cooked cassava slices, fried cassava slices, cassava flakes and the fermented cassava (cassava flour, macaroni, fufu, gaplek, composite flour, bread, tapioca, gari, cassaripo or tucupa and cassava rice) (Rashid, 2002; IITA, 2009).

Tapioca is an essentially flavourless starchy ingredient, or fecula, produced from treated and dried cassava (manioc) root and used in cooking. It is similar to sago and is commonly used to make a milky pudding similar to rice pudding. Cassava flour, also called tapioca flour or tapioca starch, can also replace wheat flour, and is so-used by some people with wheat allergies or coeliac disease. It is also used in making cassava cake, a popular pastry (Meredith *et al*., 1999:Irtwange and Achimba 2009). In Africa and Latin America, cassava is mostly used for

human consumption, while in Asia and parts of Latin America it is also used commercially for the production of animal feed and starch-based products (IITA, 2009; Echebiri and Edaba, 2008). Cassava is widely consumed in a wide range of forms by inhabitants in Nigeria. The most common forms being ‘gari’, ‘fufu’ tapioca, compo site flowers, vegetable, alcohol, starch and its pellets for livestock feeds (Agwu and Anaeyeche , 2007).

Cassava can be used as an accompaniment for meat dishes, or made into purées, dumplings, soups, stews, gravies and so on.The juice of the bitter cassava, boiled to the consistence of thick syrup and flavoured with spices, is called cassareep. It is used as a basis for various sauces and as a culinary flavouring, principally in tropical countries. It is exported chiefly from Guyana. Cassava is used in bubble drinks in East Asia The leaves can be pounded to a fine chaff and cooked as a palaver sauce in Sierra Leone, usually with palm oil but vegetable oil can also be used. Palaver sauces contain meat and fish as well (Uche *et al*., 2008).

In DR Congo the leaves are used in a stew called Pondu. Cassava is also used to make alcoholic beverages. The English explorer and naturalist, Charles Waterton was reported by Offiong *et al*., (1990) in his wanderings in South America (1836) that the natives of Guyana used cassava to make liquor, which they abandoned when rum became available. Hamilton Rice, in 1913, also remarked on liquor being made from cassava in the Brazilian rainforest.

The formation of carbon dioxide - a byproduct of yeast's respiration - causes bread to rise. Ethanol fermentation is responsible for the rising of bread dough. Yeast organisms consume sugars in the dough and produce ethanol and carbon dioxide as waste products. The carbon dioxide forms bubbles in the dough. Nearly all the ethanol evaporates from the dough when the bread is baked (Norhaizan and Nor Faizadatul, 2009).

Moreover, it has been shown that no continent depends as much on root and tuber crops in feeding its population as does Africa. In the humid and sub-humid areas of tropical Africa, cassava is either a primary staple food or a secondary co-staple. In Ghana, for example, cassava and yams occupy an important position in the agricultural economy and contribute about 46% of the agricultural Gross Domestic Product (GDP) (Offiong 1990; Uche *et al*., 2008).

1.7.2 Livestock Feed

These include: cassava pellets, cassava meal, cassava chips, cassava slices (fresh or boiled), cassava peels, cassava-leaf meal, broken roots and cassava silage. All these products are used worldwide for animal feed. The cassava hay contains high protein content (20-27% crude protein) and condensed tannins (1.5-4%). It is used as a good roughage source for dairy, beef, buffalo, goats, and sheep by either direct feeding or as a protein source in the concentrate mixtures (Oyewole and Afolami 2001; Giraud *et al*. 1992)

1.7.3 Industrial Use

Industrial products obtained from cassava include products such as starch, alcohol,glucose, acetone, dextrins, glues and pastes, binders, stabilizer, bodying agent (caramel), fillers, dusting agent (chewing gum), and single-cell protein (Agwu and Anaeyeche, 2007; Bede, 1980). In South East Asia and Latin America, cassava has taken on an economic role. Cassava starch is used as a binding agent, in the production of paper and textiles, and as monosodium glutamate, an important flavouring agent in Asian cooking. In Africa, cassava is beginning to be used in partial substitution for wheat flour (Eugene *et al*.,2008; Ajaelu *et al*., 2008; Giraud *et al*., 1992)

Under the Development Plan for Renewable Energy in the 11th Five-Year Plan in China, the target is to increase the application of ethanol fuel by non-grain feedstock to 2 million tonnes, and that of bio-diesel to 200 thousand tonnes by 2010. This will be equivalent to a substitute of 10 million tonnes of petroleum. As a result, cassava (tapioca) chips have gradually become a major source for ethanol production. On December 22, 2007, the largest cassava ethanol fuel production facility was completed in Beihai with annual output of two hundred thousand tonnes, which would need an average of one and half million tonnes of cassava. In November 2008, China-based Hainan Yedao Group reportedly invested $51.5m (£31.8m) in a new biofuel facility that is expected to produce 33 million gallons of bio-ethanol a year from cassava plants (Eugene *et al*.,2008; Giraud *et al*., 1992)..

1.7.4 Ethno-medicinal usage

According to Hiroyasu *et al*., (1982) and Brito *et al*., (2006) cassava products are used in the following areas.

The bitter variety of *Manihot* root is used to treat diarrhea and malaria. Also, the leaves are used to treat hypertension, headache, and pain. Cubans were reported to have commonly used cassava to treat irritable bowel syndrome, the paste eaten in excess during treatment. As cassava is a gluten-free natural starch, there have been increasing incidences of its appearance in Western cuisine as a wheat alternative for sufferers of coeliac disease.

1.8 Cultivation of Cassava

Cassava is vegetatively reproduced by stem cuttings (usually around 15 cm long) and produces well on poor soils. The cuttings are planted out in the fields from the beginning of the rains.

Recommended planting pattern on ridges is 150 x 75 cm and 120 x 90 cm on the flat (IITA, 2009; Kristen *et al*., 2005).

Vegetation period depends on the variety: it ranges from 9 months (e.g. Alpin Valencia), over one year (Binti Athoumani, Ali Mtumba), to 18 months (e.g. Kigoma, Msitu Zanzibar); these are the sweet varieties; bitter varieties are Liongo (one year) and Limbanga, Lumalampuni and Mzimbitala (vegetation period of 18 months). There are new varieties under testing. Unlike sweet potatoes, cassava tubers can be stored in the soil for longer periods; this is true in particular for the bitter varieties (Kumar, 1991; Hidayat *et al*., 2002).

The application of fertilizer remains limited among small-scale farmers due to the high cost and lack of availability. Roots can be harvested between 6 months and 3 years after planting (Sarkiyayi and Agar , 2010; IITA, 2009).

1.9 The Processed Cassava Products

1.9.1 'Fufu'

Under rural preparation methods the fresh peeled roots are placed under water for about 3 days and allowed to absorb water and ferment until soft. After fermentation, the water is drained off, most of the fibres are removed and the roots are pounded in large wooden mortars until a soft mash is formed. Excess water is then extracted from the mash by placing heavy objects such as rocks on top of sacks containing the fufu. The consumer who buys fufu in the market normally adds water to the mash and sieves the mixture to remove the remaining fibres (Ravindran and Kenkpen, 1992; Uyoh *et al*., 2010).

1.9.2 Cassava Chips

Cassava chips are prepared by peeling, washing and slicing tubers into suitable sizes followed by drying. Sun drying is the simplest, most economical method but has the disadvantage of taking up a large area of ground. The partially dried chips are loaded onto fine mesh grids within the house and allowed to dry for 2 - 3 days (Ravindran and Kenkpen, 1992; Uyoh *et al*., 2010).

1.9.3 Gari/Farinha

The fresh roots of cassava are peeled and grated. The grated pulp is then put in sacks (Jute or polypropylene) and the sacks are placed under heavy stones or, pressed with a hydraulic jack between wooden platforms for 3 - 4 days to extract excess liquid from the pulp, while it is fermenting. Fermentation imparts an acidic taste to the final product. The dewatered and fermented lumps of pulp are crumbled by hand and most of the fibrous matter is removed. The remaining mass is sieved with traditional sieves (made of woven splinters of cane) or iron or polyethylene mesh (Ravindran and Kenkpen, 1992; Hahn, 1992).

After being sieved, the fine pulp is then roasted in an iron pan or earthen pot over fire. If the sieved pulp is too wet, it takes longer to roast resulting in a finished lumpy product with dull colour. Palm oil may be added to prevent the pulp from burning during roasting and to give a light yellow colour to the gari. When palm oil is not added, a white gari is produced. Palm oil contains substantial quantities of vitamin A, therefore, yellow gari is 10 - 30 percent more nutritious and expensive than white gari (Ravindran and Kenkpen, 1992; Hahn, 1992).

The garification or conversion rate of fresh roots into gari is 15 - 20 %. This value varies with cassava varieties, time of harvesting, age of plant and other environmental factors. Gari is very

popular in Nigeria and less so in Cameroon, Benin, Togo, Ghana, Liberia, and Sierra Leone. In Brazil, this method is used for the production of "farinha de madioca"(Hahn, 1992; Ravindran and Kenkpen, 1992).

The traditional method used in West Africa is to peel the roots and put them into water for 3 days to ferment. The roots then are dried or cooked. In Nigeria and several other west African countries, including Ghana, Benin, Togo, Ivory Coast, and Burkina Faso, they are usually grated and lightly fried in palm oil to preserve them. The result is a foodstuff called 'Gari' (Hahn, 1992; Kristen *et al.*, 2005).

1.9.4 Fermented and Dried Cassava Pulp ('lafun')

'Lafun' in Nigeria, 'cossette'" in Zaire and Rwanda, 'kanyanga' and 'mapanga' in Malawi, and 'makopa' in Tanzania are various names for fermented and dried cassava products. Whole or peeled roots are immersed in water for 3-4 days for fermentation and softening of the tissues. The fermenting roots are then removed and broken into small crumbs, sun-dried on mats, racks, flat rocks, cement floors or roofs of houses. Drying of the fermented roots takes 1-3 days, depending on the prevailing weather. The dried crumbs are then milled into flour (Hahn, 1992; Ravindran and Kenkpen, 1992).

1.9.5 Smoked Cassava Balls ("Kumkum")

Cassava is processed into smoked cassava balls in the same way as fermented and dried pulp is produced except that the fermented wet pulp is pounded and molded into round balls of about 4 - 7 cm diameter. These balls are then smoked and dried on a platform above the fire place in a

special structure hung above the hearth. The dark coating caused by smoke is cleaned off and the cleaned balls are milled into flour before reconstitution into fufu (Kristen *et al.*, 2005).

1.9.9 Chickwangue

"Chickwangue" is the most popular processed food from cassava in Zaire. "Myondo" and "Bobolo" in Cameroon belong to this "Chickwangue" group. Similar products are produced in Congo, Central African Republic, Sudan, Gabon, and Angola (Oyewole and Afolami 2001; Hahn, 1992). Cassava roots are peeled, steeped in water for 3-5 days to ferment and become soft. The fermented pulp is taken out and the flares are removed from it. The pulp is then heaped on racks for further fermentation or the heap is covered with leaves and pressed with heavy objects to drain off excess liquid. The pulp is then ground on a stone or pounded in a mortar to obtain a finer pulp. The fine pulp is wrapped in leaves of plantain or any plant of the Zingiberaceae family and tied firmly with fibres from banana. These are steamed in pots. Chickwangue is about 10 cm wide and 20 cm long. “Myondo” has a diameter of 1.5-2.0 cm and a length of 15 cm to 20 cm. “Bobolo” has a diameter of 2-4 cm and a length of 30-40 cm. The Gabon "Chickwangue" is smaller in size than that of Zaire (Holmes and Kennedy, 2000; Tracy, 2007).

1.9.10 Starch

Starch is obtained after cassava roots are peeled, washed and grated. The grated pulp is steeped for 2-3 days in a large quantity of water, stirred and filtered through a piece of cloth. The filtrate stands overnight and the supernatant is then decanted. The starch sediments are air-dried under shade (Kumar, 1991)

1.9.11 Dried Cassava

The roots are peeled, sliced into small pieces and sun-dried on racks or roofs for 4-5 days or sometimes up to 3 weeks, depending on the weather and the size of pieces. Later, sun-dried pieces are milled into flour. This processing system is very simple but the processed products contain considerable amounts of cyanide. This method is widely used in many areas in Africa, particularly where water supply for fermentation is seriously limited (Offiong , 1990; Ebuchi *et al.*, 2005; Harn, 1992).

1.10 Varieties of Cassava

It had been suggested that before modern research on cassava started in Nigeria in 1954 at the Food And Drugs Act And Regulations (FDAR), Ibadan, there were numerous local types of traditional clones (Akoroda and Ikpi, 1992). These varied in their tuber yields and general tolerance of prevailing pests and diseases. "Oloronto" (53101), a local cultivar from the Ibadan/Abeokuta area, was then recommended for South-Western Nigeria. It was later used in crosses in 1967 which led to the release of improved varieties such as 60444, 60447 and 60506 for the whole country (Akoroda and Ikpi,1992; Achinewhu *et al*., 1998).

Breeding work at IITA later identified improved clones which were released after 1976. Releases of the first two IITA clones, namely TMS 30211 and TMS 30395, were rapidly followed by TMS 30572, TMS 30001, TMS 300017, TMS 30110, TMS 30337, TMS 30555, TMS 4(2)1425 and others (Etudaiye *et al*. 2009).

The most commonly observed local cultivars in South-Western Nigeria are (a) "Odongbo" (b) "Oyarugba dudu" (c) "Eye dudu" which is very similar to TMS 30572 and whose origin is

suspected to be from IITA's stock and (d) "Isunikankiyan". However, the most commonly grown local variety in South-Western Nigeria is Odongbo - which bears different names in different parts of southwestern Nigeria, e.g. Jejeti in Warri, Delta state (Jonathan *et al*., 2006; Dulce *et al*., 2008)

In related literature it was shown that there is a great variation in toxicity between cultivars. A distinction is usually made between "sweet" cultivars with relatively low contents of cyanogenic glycosides (below 10 mg/100g of fresh weight), and "bitter" cultivars with high cyanogenic glycoside content (above 20 mg/100 g fresh weight), although many intermediate forms exist. Traditionally, the sweet cultivars were considered non-toxic while the bitter ones were considered toxic (Paula *et al*., 2005).

IITA, Nigeria (2008), developed a new variety of cassava known as TMS92/0067 that is well-adapted to the dry or drought-prone conditions of the semi-arid zones of sub-Saharan Africa. The variety, with farmer management, produces an average of 30 to 50 tonnes of cassava per hectare as opposed to the 5 tonnes per hectare from local varieties commonly used by farmers in these areas (IITA, 2008).

The Central Agricultural Research Institute (CARI), Suakoko in Bong County of Liberia which has partially been financed by the International Development Research Centre (IDRC) of Canada, developed cassava varieties for high yields, disease resistance and root quality. Three high yielding varieties, CARICASS I, CARICASS II, and CARICASS III have been proven to be superior to the local variety, both at on-station and on-farm trials (Ravindran and Kenkpen,1992). The acceptance and cultivation of high yielding cassava varieties like CARICASS I, CARICASS II and CARICASS III by farmers would naturally increase national

production levels of cassava in Liberia. Higher production of cassava may lead to its increased utilization as animal feed (Ravindran and Kenkpen,1992) .

Investigations carried out by Agwu and Anyaeche (2007) revealed that majority (64%) of the farmers from Ukpor, Amichi, Osumenyi, Ezinifite, Ekwulummili and Ebenator communities in Nnewi South Local Government Area of Anambra State, Nigeria cultivated both local and improved cassava cultivars. The improved cassava cultivars grown by the farmers were TMS 30572, TMS 30555 and TMS 4(2) 1425 while 'akpuocha', 'udukanani' and 'achirinaka' were the most popular local cultivars grown in the area. (Agwu and Anyaeche, 2007).

Agwu and Anyaeche (2007) reported that there are about 17 cassava cultivars (TMS 90257, TMS 84537, TMS 82/00066, TMS 82/0066, NR 6212, NR 8082 TMS 50395, TMS 30001, NR 6208, NR 6083, TMS 81/00110, TMS 91934, TMS30672, TMS 4(2) 1425, TMS 30655, NR 83107, and NR 41044), with a wide range of ecological adaptability, released for cultivation in Nigeria

According to Okeke (1992) and Oluwole *et al.* (2007), of the wide varieties of cassava (TMS 50395, TMS 91934, NR8267, NR8212 and TMS 30572), TMS 30572 is the most widely adopted in Nigeria because of its good food quality characteristics, disease resistance and yield superiority over the native cultivars .

1.11 The Anti-Nutritional Factors

Although, acyanogenic roots were reported prior to 1940, this has never been confirmed, but roots containing only 1–2 µg/g have been reported. At the other extreme there are reports of total cyanide levels of 1090 and 1550 µg/g in Tanzania, mean values of 1100 µg/g in India and 454

µg/g in the Amazon. The range of total cyanide contents of root parenchyma is therefore 1–1550 µg/g (Paula *et al*., 2005).

Ccassava plant is a nutritionally strategic famine crop for developing countries and, therefore, reducing its toxicity and improving its nutritional value is crucial (Julien *et al.*, 2008).

1.11.1 Cyanide

Cyanide is the most toxic factor restricting the consumption of cassava roots and leaves. Indeed, cassava, particularly its bitter varieties, has a cyanide level higher than the FAO/WHO (1991) recommendations, which is < 10 mg cyanide equivalents/kg DM, to prevent acute toxicity in humans. Cassava leaves have a cyanide content ranging from 53 to 1,300 mg cyanide equivalents/kg of DW, and cassava root parenchyma has a range of 10 to 500 mg cyanide equivalents/kg DM; both of these are much higher than what is recommended (Hidayat *et al.*, 2002; Hiroyasu *et al*.,1982). Cyanide is very poisonous because it binds cytochrome oxidase and stops its action in respiration, which is a key energy conversion process in the body. The lethal dose for an adult depends on body weight and is between 30 and 210 mg of hydrogen cyanide.

Sometimes persons eating a cassava meal exceed these limits and deaths occur due to cyanide poisoning. Smaller (non-fatal) amounts of cyanide cause acute intoxication with symptoms of dizziness, headache, stomach pains, vomiting and diarrhea (Julien *et al.*, 2008).

Several health disorders and diseases have been reported in cassava-eating populations. Consumption of 50 to 100 mg of cyanide has been associated with acute poisoning and has been reported to be lethal in adults. The consumption of lower cyanide amounts are not lethal but long-term intake could cause severe health problems such as tropical neuropathy, glucose

intolerance, konzo (spastic paraparesis), and, when combined with low iodine intake, goitre and cretinism may result (Paula *et al*., 2005)

The highest proportion of HCN is found in the peels and the cortex layer immediately beneath the peels. It is for this reason the cassava root is always peeled before being processed or consumed (Hahn, 1992). Since HCN is soluble in water and has a boiling point of 25°C it can be removed by soaking. Boiling fresh cassava has little effect on its toxicity as the glycoside limamatine is heat resistant and the enzyme linamarase is inactivated at 75°C (Hahn, 1992).

Cyanide are produced from cyanogenic glycosides. Cassava produces two cyanogenic glycosides; linamarin and a small amount of lotaustralin (methyl linamarin) which are considered "bound" (Paula *et al*., 2005; FAO, 1990; Kumar 1992; Padmaja, 1995). In the whole unbruised plant the cyanogenic glucoside remains intact in the form of linamarin and lotaustralin. When the cellular structure is disrupted, the intracellular glucoside becomes exposed to the extracellular enzyme linamarase. Hydrocyanic acid (HCN) is then produced (Tewe, 1992).

These cyanogens are distributed widely throughout the plant, with large amounts in the leaves and the root cortex (skin layer), and generally smaller amounts in the root parenchyma (interior) Wanda *et al*., 1998; Kirsten *et al*., 2011).

Cyanogens can be hydrolysed or converted by enzymes known as linamarase (glucosidases) and hydroxynitrile lyases (produced when there is a damage to or rapturing of the plant) to form acetone cyanohydrin (x - hydroxynitrile), which is unstable above pH 5, and hydrolyses to HCN or prussic acid and acetone (Kumar, 1992; FAO, 1990; Hahn, 1992; Kristen *et al*., 2005; Tewe, 1992). The acid is shown to be a volatile compound and toxic (Dulce *et al.,* 2008; Tewe, 1992;

FAO, 1990). However, under acid conditions of pH 4 or less, which tend to occur in some lactic acid fermentations of cassava, the cyanohydrin decomposition is hindered and it becomes stable (FAO, 1990).

Linamarin + water + linamarase →cyanogenic acid + acetone + glucose (Tewe, 1992; Kirsten *et al*., 2011).

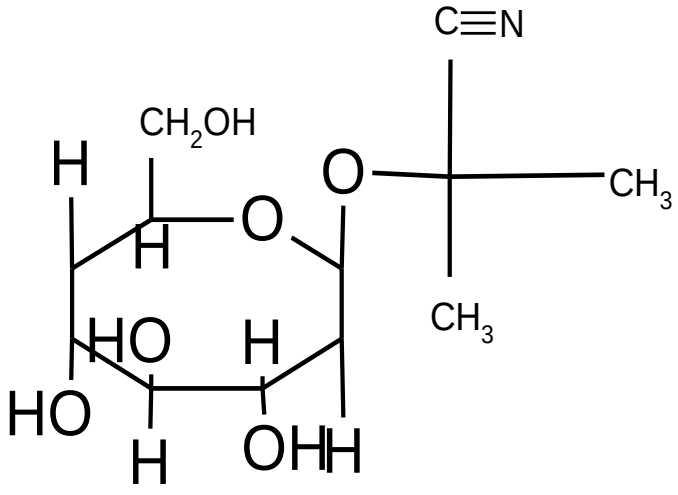


Figure 1.1: Sructure of linamarin

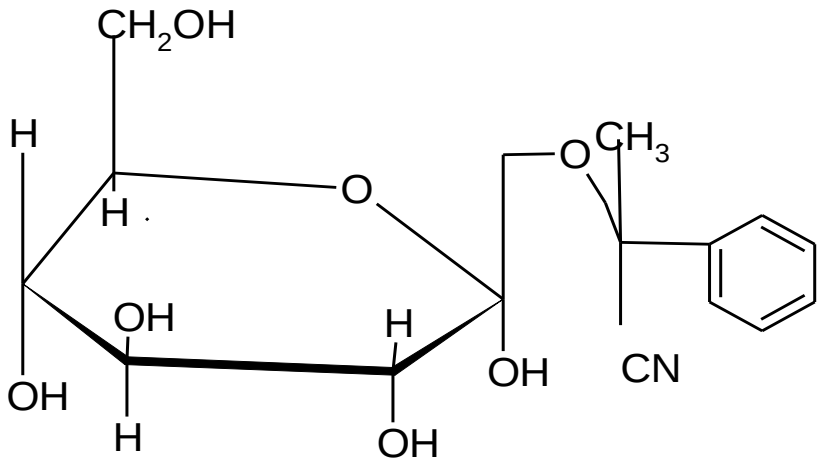


Figure 1.2: Structure of lotaustralin

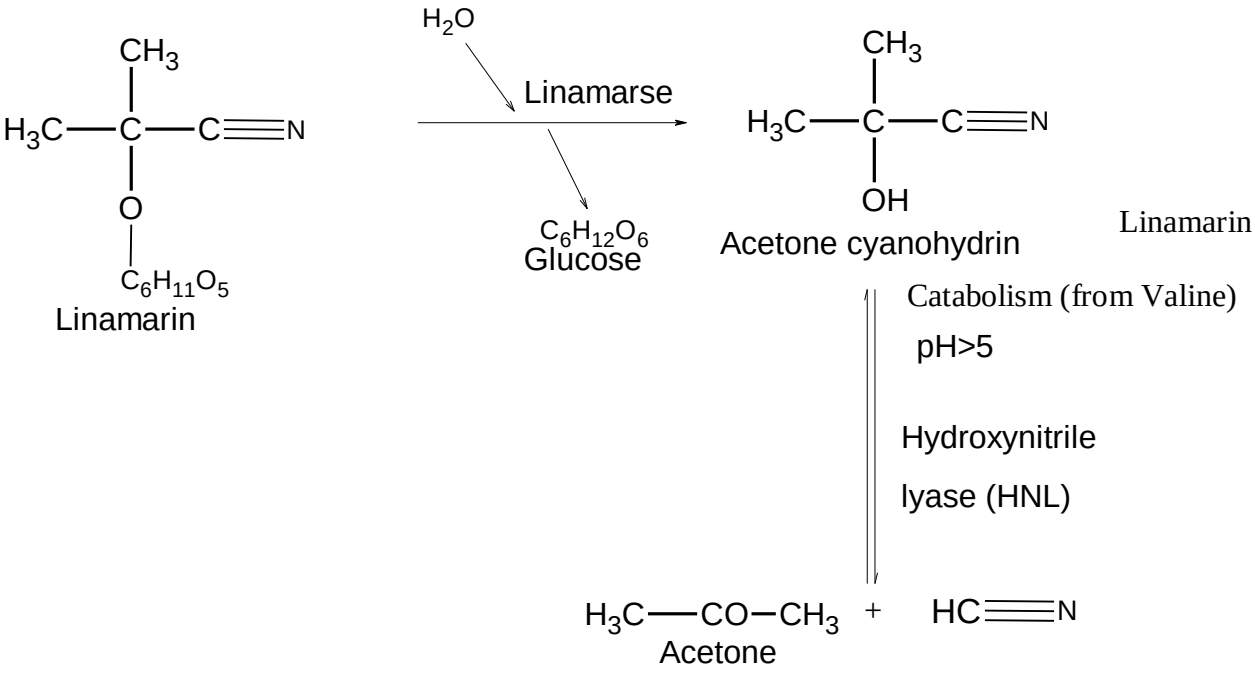
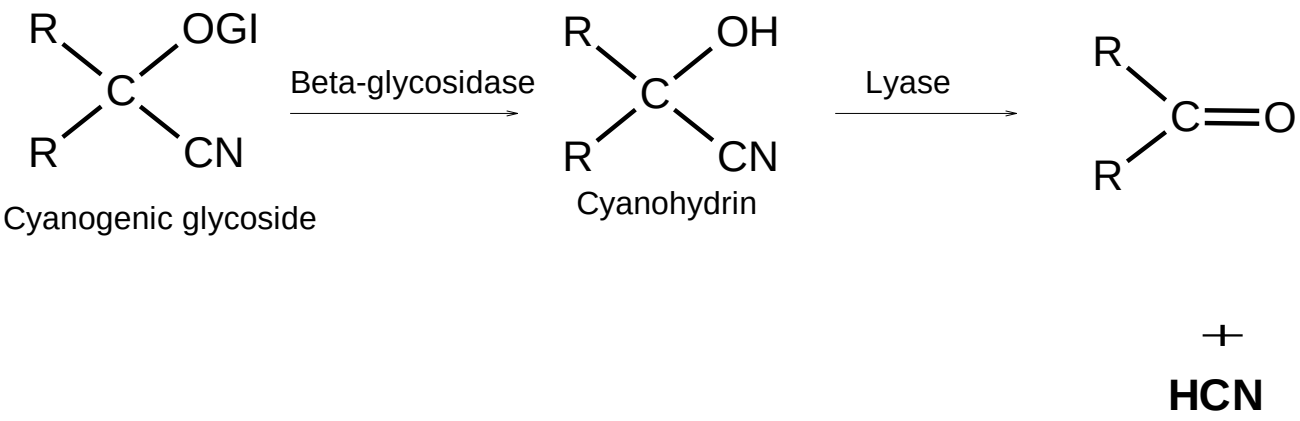


Figure 1.3: Llinamarin catabolism (from Valine)



Cyanogenic glycoside

Figure 1.4: Cyanogenic glycosides catabolism

HCN evaporates rapidly in the air at temperatures over 28^{o} C and dissolves readily in water. It may easily be lost during analysis of specimens (Kumar,1992; FAO, 1990; Jonathan *et al.,* 2006).

In spite of the relative instability of cyanohydrin it coexists with intact glycoside and HCN in differently processed cassava products. It is therefore clear that the cyanide in cassava products exists in three forms: (i) the glycosides (95% linamarin and 5% lotaustralin), (ii) the cyanohydrin and (iii) the free hydrocyanic acid (HCN) (FAO, 1990: Julien *et al,*. 2008). Free cyanide comprises 8%-12% of the total tuber cyanide. This cyanide can, under some circumstances, lead to human toxicity problems and cassava for food use has to be processed to remove cyanide-containing substances (FAO, 1990).

Linamarin is a rather stable compound which is not changed by boiling the cassava. If it is absorbed from the gut to the blood as the intact glycoside it is probably excreted unchanged in

the urine without causing any harm to the organism. However, ingested linamarin can liberate cyanide in the gut during digestion (FAO, 1990).

Linamarin is present in large amounts in the leaves and the peel of the roots (900 – 2000 mg HCN equivalents kg^{-1} fresh weight) and the leaves also contain a second enzyme called hydroxynitrile lyase, which catalyses the hydrolysis of acetone cyanohydrin (x - hydroxynitrile) to produce HCN and acetone (Dulce *et al.,* 2008; FAO, 1990 ; Agbo-Egbe *et al*., 1995). The normal range of cyanogen content of cassava tubers falls between 15 and 400 mg HCN/kg fresh weight. The concentration varies greatly between varieties and also with environmental and cultural conditions. The concentration of the cyanogenic glycosides increases from the centre of the tuber outwards. Generally the cyanide content is substantially higher in the cassava peel. Bittemess is not necessarily a reliable indicator of cyanide content (FAO, 1990).

Exposure to high levels of cyanide for a short time harms the brain and heart and can even cause coma and death. Workers who inhaled low levels of hydrogen cyanide over a period of years had breathing difficulties, chest pain, vomiting, blood changes, headaches, and enlargement of the thyroid gland (The Poisonous Cyanide in Cassava, 2009).

1.11.2 Recommended dietary allowance (RDA) for cyanide

The normal range of cyanogen content of cassava tubers falls between 15 and 400 mg HCN/kg fresh weight (FAO, 1990). Hahn (1992) reported cyanide levels in the range 6 to 370 mg/kg depending on the particular cultivar, growing conditions, (i.e. soil type, humidity, temperature) and the age of the plant. An intake of over 20 mg per 100 g of cassava is toxic, while others set the toxic level at an intake of 50 to 60 mg daily for an European adult (FAO, 1990). The lethal

dose range for humans of hydrogen cyanide taken by mouth for a 60 kg adult amounts to 30 – 210 mg of HCN. The lethal dose is shown to be proportional to body weight (Dulce *et al*., 2008; Kumar, 1992). According to Hahn (1992), the lethal dose of free HCN for an adult is 50-60 mg

The bitterness is largely due to linamarin, but other bitter and sour components present may confuse the taste buds, hence this taste test is not always an effective warning system against the use of poisonous roots. In other words. there is no direct correlation between toxicity and taste (Paula *et al*., 2005; Hahn, 1992).A useful guide based on total root cyanide content used by and others is: innocuous 0-50 ppm, moderately poisonous 50 – 100 µg/g and dangerously poisonous >100 µg/g. The dangerous nature of very high cyanide varieties is underlined by the name of one variety in Nigeria that is called 'chop and die'(Paula *et al.*, 2005).

The World Health Organisation (WHO) has set the safe level of cyanogens in cassava flour at 10 ppm and the acceptable limit in Indonesia is 40 ppm (Paula *et al.,* .2005). A dose 40 mg of pure cassava cyanogenic glucoside has been shown to be sufficient to kill a cow (Emmanuel, 2002).

1.12 Phytate

Phytate (inositol hexakisphosphate) is another compound found in high abundance in cassava, with approximately 624 mg/100 g in roots .It is a storage form of phosphorus and a general term used to describe hexaphosphate esters of inositols (Montagnac *et al.,* 2009). Phytic acid is able to bind cations such as magnesium, calcium, iron, zinc, and molybdenum and can, therefore, interfere with mineral absorption and utilization which may affect requirements. It may also bind proteins preventing their complete enzymatic digestion (FAO, 1990; Emmanuel *et al.,* 1990). Phytic acid not only grabs on to or chelates important minerals, but also inhibits enzymes that we

need to digest our food: including pepsin, needed for the breakdown of proteins in the stomach, and amylase, needed for the breakdown of starch into sugar. Trypsin, needed for protein digestion in the small intestine, is also inhibited by phytates (Rami, 2010).

However, phytic acids also have antioxidant and anticarcinogenic properties (FAO, 1990. Indeed, phytic acids can reduce free ion radical generation and thus peroxidation of membranes by complexing ion, and phytate may protect against colon cancer. Phytate was able to reduce serum cholesterol and triglycerides in an animal model fed a cholesterol-enriched diet. Dephosphorylation of phytate occurs during processing of cassava, especially during fermentation when > 85% of phytate is removed (FAO, 1990; Emmanuel *et al.,* 1990).

A diet high in phytate-rich grains has many powerful anti-nutritional effects. Many health problems can result: including tooth decay, nutrient deficiencies, lack of appetite and digestive problem (Rami , 2010).

1.12.1 The phytate threshold

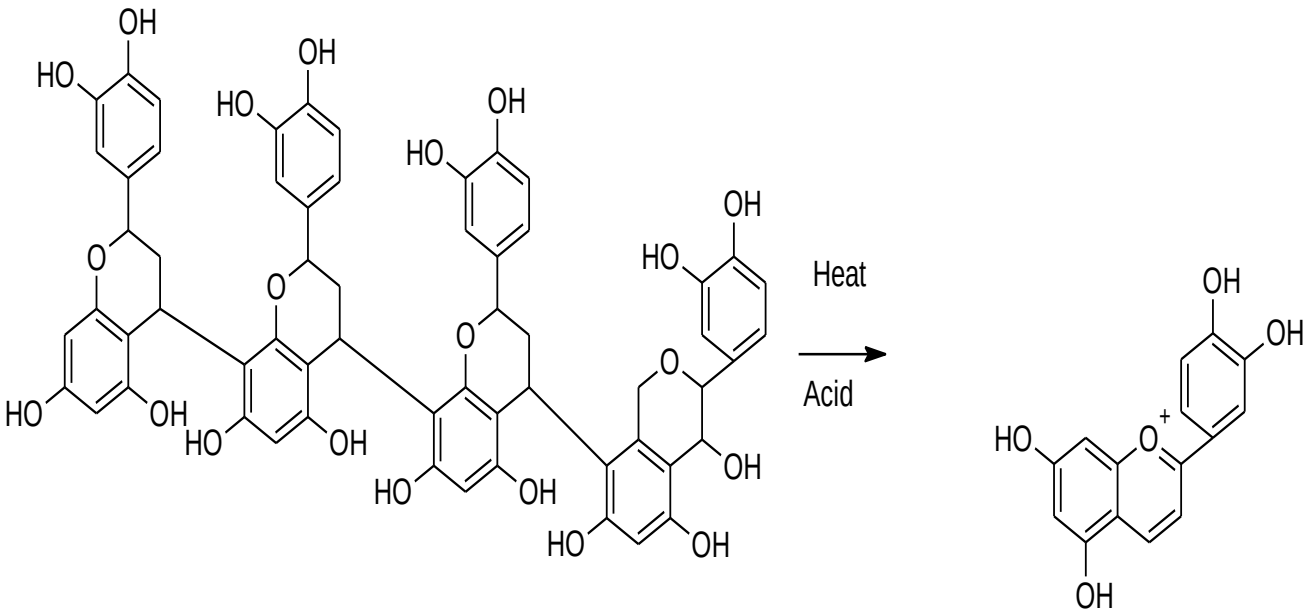
It appears that once the phytate level has been reduced, such that there is more available phosphorus than phytate in the grain, we have passed a critical point and the food becomes more beneficial than harmful. Retention of phosphorus decreases when phytate in the diet is 30-40 percent or more of the total phosphorus.

For best health, phytates should be lowered as much as possible, ideally to 25 milligrams or less per 100 grams or to about .03 percent of the phytate-containing food eaten. At this level, micronutrient losses are minimized (Rami, 2010; Adeyeye *et al*., 2000).

1.13 The Polyphenols (Tannins)

Tannins are water soluble phenolic compounds with a molecular weight greater than 500 and with the ability to precipitate proteins from aqueous solution. They occur almost in all vascular plants (Kumar,1992; Montagnac *et al.,* 2009).

Hydrolysable tannins and condensed tannins (proanthocyanidins) are two different groups of these compounds. Generally tree and shrub leaves contain both types of tannins. The two types differ in their nutritional and toxic effects. The condensed tannins have a more profound digestibility-reducing effect than hydrolysable tannins, whereas the latter may cause varied toxic manifestations due to hydrolysis in rumen (Kumar, 1992; Montagnac *et al.,* 2009). Further reports by Kumar (1992) linked the mechanism of dietary effects of tannins to their ability to form complex with proteins. Tannins might form a less digestible complex with dietary proteins and might bind and inhibit the endogenous protein, such as digestive enzymes. Tannin-protein complexes involve both hydrogen-bonding and hydrophobic interactions; the precipitation of the protein-tannin complex depends upon pH, ionic strength and molecular size of tannins. Both the protein precipitation and incorporation of tannin phenolics into the precipitate increase with the increase molecular size of tannins. (Kumar 1992; Montagnac *et al.,* 2009).



Proanthocyanidins **Anthocyanidins**

Figure 1.5: Structures of proanthocyanidins and anthocyanidins

1.13.1 Interaction of tannins with other macromolecules

Tannins have a major impact on animal nutrition because of their ability to form complexes with numerous types of molecules, including, but not limited to carbohydrates, proteins, polysaccharides, bacterial cell membranes, enzymes involved in protein and carbohydrates digestion (Kumar 1992; Céline et al., 2010; Savolainen, 1998).

1.14 Oxalates

Oxalic acids (also referred to as oxalates) are found in many foods. They are naturally occurring chemicals in plants and animals and are also consumed in a variety of different foods such as leafy greens, nuts, seeds, most berries, certain fruits, soy and soy products, meat and dairy products. In large amounts, oxalic acid is poisonous, but toxic levels are not found in foods that we normally eat (Tracy, 2007).

Oxalates are anti-nutrients affecting calcium and magnesium bioavailability and form complexes with proteins, which inhibit peptic digestion (Montagnac *et al.,* 2009). The IUPAC name for oxalate is ethanedioate and is the dianion with formula $C_2O_4^{2-}$, also written as $(COO)_2^{2-}$. Oxalate-rich plants include fat hen ("lamb's quarters"), sorrel, and several Oxalic species. The root and/or leaves of rhubarb and buckwheat are high in oxalic acid. Other edible plants that contain significant concentrations of oxalate include — in decreasing order — star fruit (carambola), black pepper, parsley, poppy seed, amaranth, spinach, chard, beets, cocoa, chocolate, most nuts, most berries, fishtail palms, New Zealand spinach and beans (Tracy, 2007).

1.15 Saponins

Kumar (1992) indicated that saponins are glycosides containing a polycyclic aglycone moiety of either C_{27} steroid or C_{30} triterpenoid (collectively termed as sapogenins) attached to a carbohydrate. They are kown to be widely distributed in the plant kingdom. The anti-nutritional effects of saponins have been mainly studied using alfalfa saponins (FAO , 1990).

The yuca (cassava) root contains high levels of a phyto-compound, called saponins which acts as a natural steroid. When the compound is extracted from the yuca it makes a perfect natural soap or shampoo (Kumar, 1992). They have antitumor properties and may offer synergistic effects when used in combination with drug therapy. Saponins can also act on the central nervous system of humans with potential therapeutic effects (Montagnac *et al.,* 2009). Cassava leaf meal has a steroidal saponin content ranging from 1.74 to 4.73 g/100 g DM, which compares to those found for soybeans (0.07 to 5.1 g/100 g DM), but is lower than those observed in alfalfa (5.6 g/100 g DM) and beet leaves (5.8 g/100 g DM). Saponin content increases in cassava leaf meal with plant maturity (Montagnac *et al.*, 2009).

1.15.1 Recommended dietary allowance (RDA) for cyanide

Ryokucha saponin (RSP), which is one of the ingredients of green tea was shown to have the no-effect level as 50 mg/kg/day and the lowest-observed-effect level of 150 mg/kg/day for consumption, so that the true no-effect level of RSP was estimated to be between these dose levels (Kawaguchi *et al*., 1994).

1.16 Effects of Environmental Conditions on the Nutritional and Antinutritonal Composition of Cassava Products

The characteristics of the sets of cassava varieties grown by farmers and their adjustment pattern over time depend mainly on production objectives which are mostly dictated by environmental and socio-economic conditions (Coffi *et al*., 1992).

Age, variety, and environmental conditions influence the occurrence and concentration of HCN in various parts of the cassava plant and at different stages of development (Kumar, 1992).

The total cyanide content of cassava parenchyma is dependent on the cultivar, the environment and various other factors.Cyanide levels in the range 6 to 370 mg/kg have been found depending on the particular cultivar, growing conditions, (i.e. soil type, humidity, temperature) and the age of the plant (FAO, 1990; Paula *et al*., 2005).

Eugene (2008) studied the effect of environmental variations by carrying out proximate composition and energy values of four raw and heat processed staple foods (yams, cassava, cocoyam and maize) from oil-producing (Eleme, Ogoni, Okrika, and Nembe) areas of Rivers and Bayelsa States and Abakaliki (a non-oil producing area in Ebonyi State, Nigeria) as control. In each of these locations, heat processing generally increased moisture content of all the samples (yam, cassava products, cocoyam and maize), but decreased dry matter, crude protein, ash, crude fat, total carbohydrate and calorific value. With the exception of moisture and ash, the composition of the other nutrients were significantly ($p < 0.05$) higher in the control area of Abakaliki than for the values obtained in similar samples from oil producing areas of the Niger Delta investigated. The amount of rainfall has been proved to affect total cyanide levels (Paula *et al*., 2005)

Total cyanide levels in roots were shown to increase in a year of low rainfall or drought due to water stress on the plant. The effect of low rainfall has been to greatly increase the total cyanide content of the flour.In areas of eastern, central and southern Africa, where flour isproduced by sun drying/heap fermentation, the cyanide content is too high in a normal year, but the situation becomes very serious in years when rainfall is low, a recurring feature of the climate (Paula *et al*., 2005; Kapoor et al., 2006).

Steven and Oluwole (2008) investigated the cyanogenicity of cassava varieties and risk of exposure to cyanide from cassava food in Nigerian communities. This study was conducted in four geographical areas of Nigeria (northern, southwestern, southeastern and an area endemic for ataxic polyneuropathy) to determine if cyanogenicity of cassava is associated with geographical area or level of cyanogenic compounds in gari, a popular cassava food in West Africa (Steven and Oluwole, 2008).The findings showed that mean levels of cassava cyanogens were 153, 127, 68 and 65 mg HCN equivalents kg^{-1} dry weight (DW) in the endemic, southeastern, southwestern and northern areas respectively ($P < 0.0001$), while mean levels of gari cyanogens were 9, 4, 7 and 13 mg HCN eq. kg^{-1} DW in the respective areas ($P < 0.0001$). The findings discovered that cyanogenicity of cassava is determined by environmental factors rather than by conscious selection of varieties by farmers. Farming high-cyanogenic cassava is not associated with high levels of residual cyanogens in gari (Steven and Oluwole, 2008).

1.17 Aim of the Study

The research aim is to investigate the effects of microbial fermentation on the proximate, mineral and antinutritional constituents of some selected varieties of cassava products.

1.18 Objectives of the Study

The objectives are to:

(1) determine the nutritional and anti-nutritional contents of the products of some selected varieties of cassava (*Manihot esculenta*);

(21) see the effects of microbial fermentation on the nutritional and anti-nutritional compositions of the products aimed at reducing the toxicants to tolerable levels and improving nutritional status of the cassava products;

(3) evaluate the effects of geographical variations on the constituents of *Manihot esculenta* planted in three selected parts of Niger State, Nigeria;

(4) assess the effect of varietal differences on the nutritional compositions of the cassava products; and

1.19 Justification for the Study

The ever-increasing consumption of cassava and its products due to its ease of propagation, processing and consequently its affordability by all, necessitate research on how best to enhance its nutritional compositions and reduce the hazardous anti-nutritional complications through effective processing techniques.

Geographical location, rain fall pattern and the nature of soil determine the composition of the products to be obtained from cassava, as a result the products were sourced from different environment for comparative study.

Since consumption of cyanide is associated with some diseases, efforts toward eradicating such diseases would be a very welcome development. So there is need to identify the varieties with high toxins, and the best processing technique needed to reduce these to a tolerabe level.

In addition, to the best of my knowledge, no similar work has been reported for Niger state, the area under investigation.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Methods of Improving Nutrient Contents of Cassava Products (Fortification)

According to Festus and Nouba (1995) and also opined by Oboh and Elusiyan (2007), there are two principal methods available for increasing the nutrient contents and amino acids of fermented cassava products. First, through controlled fermentation, microflora could be made to grow in large numbers in the mash before fermentation. For example, the microorganisms in palm wine are known to comprise of yeasts, predominantly *Saccharomyces sp*. and a wide range of bacteria, including the lactic acid and acetic acid bacteria, *Bacillus, Corynebacterium* and *Staphylococcus*. When palm wine stands, microorganisms in it tend to settle to the bottom of vessels in which the wine is contained. The high density of this portion of the drink, which may constitute up to 20% of the total volume of the drink, makes it unpalatable. This valuable protein-rich biomass is thus discarded after the supernatant is drunk (Oboh and Elusiyan, 2007).

Some of the organisms that have been successfully utilized as pure cultures to enrich the protein and amino acid content of gari are yeasts and lactic acid bacteria which naturally occur in palm wine (Oboh and Elusiyan, 2007). Given the high concentration of these organisms in the dregs, palm wine could serve as inoculum for protein and amino acid enrichment of gari and similar starchy foods produced by fermentation. This inoculum, unlike pure cultures proposed earlier, would be readily available to the traditional processor. Fermentation was found to be one of the oldest applied biotechnologies, having been used in food processing and preservation as well as beverage production for over 6,000 years. It enhances the nutrient content of foods through the

biosynthesis of vitamins, essential amino acids and proteins, by improving protein quality and fibre digestibility. It also enhances micronutrient bioavailability and aids in degrading anti-nutritional factors. This method of upgrading the protein content of cassava had been developed in some countries.

Solid media fermentation of cassava products is presently practised in Canada where *Aspergillus fumigates* were used, in Burundi and Nigeria where *Rizopus oryzae* was used in enriching cassava products with proteins. Recently, Oboh and Elusiyan (2007) reported that *Saccharomyces cerevisae* (10.5%) could also be used for enriching cassava products. Furthermore, cassava products enriched by this method have thus far been destined only for animal feed, due to the high risks involved in microbial manipulations.

The second method involves adding protein to the deficient food from external sources in such a way as not to alter significantly the organoleptic qualities of the original food. This method has an advantage over the first because of the open choice of protein sources, its simplicity for use by groups with low technological capabilities, and its relative cheapness (Oboh and Elusiyan, 2007).

The third method is by interspecific hybridization with a wild specie known for its higher protein content. This has raised an increasing interest in sourcing for wild species, collecting them and screening them for protein content (Nagib and Costa, 1977).The authors reported that cattle and horses do eat the vegetative parts and tubers of these species when grazing on natural habitat.

Similar investigations by other scientists have indicated how cassava plant products fortified with enough vitamins, minerals and protein to provide the poor and malnourished with today`s

worth of nutrition in a single meal. It is in this regard that the reports of the American Chemical Society (2007) indicated that the fortified cassava could provide a day's nutrition in a single meal.

This is in line with the fact that majority of people who eat cassava products as staple food are poor, and often cannot afford the protein component of fish or meat required to balance cassava meals, since it has a rather low protein content (1 - 2%). Additionally, cassava products are known to contain residues of cyanogenic glycosides, which with its prolonged consumption, particularly in low protein diets have been reported to lead to diseases such as tropical ataxic neuropathy and goiter.

Horace and Carlos (1982) reported the use of cassava as a methionine carrier to balance the diet of the people of North East Brazil. Their typical diet consists of a large amount of cassava as a source of calories and beans as a source of protein. Bean protein has a low methionine content and so the addition of methionine improves the nutritive value of the diet. Products such as bread made from a mixture of cassava-flour and soy flour and tapioca macaroni have been some of the most promising protein-enriched products prepared from this very important root crop.

In the Caribbean area and other tropical countries, dishes or products such as bammy, patties, fritters, dumplings, grits, bread and pudding were supplemented with protein from soybean, peanut or cheese whey. This was reported to have been able to fill a substantial part of the daily protein requirement of people in these areas (Horace and Carlos, 1982).

2.1.1 Nutritional enhancement of cassava products through microbial fermentation

Ogbo *et al*. (2009) carried out research work to determine the suitability of the biomass contained in the dregs of palm wine, an alcoholic beverage, as an alternative to pure cultures of microorganisms as inocula for improving the protein and amino acid content of 'gari'. The results showed that protein composition of 'gari' was improved significantly.

Nguyen *et al*. (2002) evaluated fermentation procedure to increase the protein content of cassava bran with *Aspergillus niger*. The organism was grown in a cassava bran medium with different inorganic nitrogen (ammonium tetraoxosulphate (VI)) levels (0, 0.5 1.0 and 1.5%N in DM) and fermented for 144 hr (Nguyen *et al.*, 2002). The results indicated the true protein contents as 3.3, 5.2, 6.4 and 5.1% in DM, for the four levels of ammonium sulphate, respectively, with greatest increase with the addition of 1% of ammonium sulphate. Similar results were obtained with the fungus, *Trichoderma pseudokonigii rifa* using the minimum of nutrients (0.15% $(NH_4)_2SO_4$).

Changes in the protein of three agro-industrial by-products (cassava peels (CP)), brewers dried grain (BDG), and maize offal (MO)) after fermentation with *Aspergillus niger, Aspergillus flavus* and *Penicillium sp.* in solid state were determined by Eustace (2004). The crude protein of the BDG, MO and CP were shown to increase significantly ($P < 0.05$). After 14 days, the highest percentage increase in protein (41%) was obtained in CP inoculated with *A. niger*. Antai aand Mbongo (2005) inoculated mash prepared from cassava peels with either *Sacchromyces cerevisiae* or *Candida tropicalis* and then left to ferment for 7 days. Chemical analysis of the fermented mash showed substantial increase in crude protein content and decrease in carbohydrate content of the mash. It was further observed that, when the mash was supplemented with inorganic nitrogen sources (urea, ammonium sulfate or sodium nitrate) before

commencement of fermentation, the amount of crude protein formed was almost doubled. This enhanced crude protein production was highest in the mash supplemented with urea.

Oboh *et al.(*2002) evaluated gari and cassava flour fermented with pure strain of *A. niger*. The results of the proximate analysis revealed that there was a significant increase ($P < 0.05$) in the protein content (flour (12.2±0.2%) gari (7.3±0.1)). Conclusively, the results of the study showed that *Aspergillus niger*, a cheap, non-pathogenic saprophyte, has the capability to increase the nutritional potential of cassava products by increasing the protein and fat contents present in them.

An investigation to enrich the nutrient of cassava peels using a mixed culture of *Saccharomyces cerevisae* and two bacteria namely *Lactobacillus delbruckii* and *Lactobacillus coryneformis* was carried out by Ganniyu (2006). Cassava pulp was fermented with pure strains of the microorganisms for 3 days. The squeezed liquid from the fermented pulp was used to ferment cassava peels for 7 days. Analysis of the dried fermented peels revealed that there was a significant ($P < 0.05$) increase in the protein content of the cassava peels fermented with squeezed liquid from the inoculated cassava pulp (21.5%) when compared with the unfermented cassava peel (8.2%).

The analysis of flour and gari processed from cassava pulp inoculated with *Saccharomyces cerevisae* was carried out by Oboh and Akindahunsi, (2003). The result revealed that there were significant increase in the protein (flour (10.9%), gari (6.3%)) It could be inferred that *Saccharomyces cerevisae*, a cheap and non-pathogenic saprophytic aerobe, has been shown to enhance the nutritional potential of cassava products by increasing nutrient (protein) (Oboh and Akindahunsi, 2003).

Gari was prepared from cassava mash inoculated with 0, 1, 5 and 10% (v/w) of palm wine dregs just before dewatering and fermentation and analyzed for protein content and other characteristics by Ogbo *et al.(*2009). Inoculation with palm wine dregs increased microbial activity in cassava mash, particularly the activity of lactic acid bacteria. The results showed that protein composition of gari was improved. Inoculation adversely affected mineral composition (Ogbo *et al.*, 2009).

Oboh and Elusiyan (2007) carried out comparative studies on the ability of pure strain of *Rhizopus oryzae* and *Saccharomyces cerevisae* to alter the nutritional quality of cassava flour produced from low- and medium-cyanide variety of cassava tubers. The proximate, mineral and the anti-nutrient composition of the cassava flour were determined. The results of the study revealed that the unfermented flour from low-cyanide cassava variety had higher protein, fibre, ash, fat, Ca, Na and K contents, while those produced from medium-cyanide variety, had higher anti-nutrients (tannin, cyanide and phytate), Zn, Mg and Fe contents. However, solid substrate fermentation of the cassava mash using *R. oryzae* and *S. cerevisae*, independently, caused a significant ($P < 0.05$) increase in the protein and fat content. The nutrient enrichment was significantly higher ($P < 0.05$) in flour produced from low-cyanide cassava variety. In addition, S. cerevisae fermentation brought about a higher increase in the nutrient content than *R. oryzae* fermentation. Conversely, fermentation of the cassava caused a significant decrease ($P < 0.05$) in the anti-nutrient content of the flour; although, the level of decrease was more in the flour produced from low-cyanide variety than medium-cyanide variety (Oboh and Elusiyan, 2007).

Candida utilis strain BKT4 and *Saccharomyces cerevisiae* strain BKT7 isolated from burukutu (a local wine brewed from sorghum) were used to enrich fufu as evaluated by Fagbemi and Ijah

(2006). From the results, there were changes in the microbiological and biochemical characteristics of the cassava during the fermentation process. The total viable counts increased with increasing fermentation time while the counts of the lactics and fungi increased at the later stages of the fermentation due to the acidity of the medium. Various bacteria (*Bacillus, Staphylococcus, Klebsiella, Escherichia, Streptococcus, Lactobacillus, Leuconostoc, Corynebacterium*), moulds (*Penicillium, Aspergillus, Fusarium, Mucor, Rhizopus*) and yeasts (*Candida, Saccharomyces, Hansenula, Rhodotorula*) were found to be associated with the fermentation process (Fagbemi and Ijah, 2006). The pH of the fermented cassava increased from 4.2 to 5.7 after 72 h, while the cyanide level decreased from 2.2 mg/kg to 0.7 mg/kg over the same period of fermentation. Fufu (prepared by crushing and sieving fermenting cassava roots) enriched with 0.5 g of C. utilis strain BKT4, S. cerevisiae BKT7 and a mixed culture of the two organisms revealed a crude protein of 7.90, 6.34 and 10.0% respectively as compared to 2% protein content of the enriched fufu. There was a corresponding increase in protein content of the product as the quantity of the enrichment yeast was increased from 0.5 to 3.0 g (Fagbemi and Ijah, 2006). The aroma of the enriched fufu was preferred to that of the commercial fufu. Generally, good acceptability and organoleptic qualities (colour, taste, texture and aroma) of the protein enriched fufu was best achieved within 48 h of enrichment. The results of this study suggest that fufu can be made more nutritious with yeasts, particularly *C. utilis* strain BKT4 and *S. cerevisiae* strain BKT7 (Fagbemi and Ijah, 2006).

Studies were carried out by Andrew and Peter (1980) on the production of microbial protein from cassava using *Trichoderma reesei* and yeast. In monoculture studies, *T. reesei* was grown on whole cassava medium to give 0.74 g dry cell/g cassava. The dry material contained 42% protein. Mixed culture fermentation was also carried out with the two microorganisms. Besides

accelerating the rate of degradation and conversion of cassava to cells (0.85 g cell/g cassava) the yeast boosted the protein content of the growth product to 51% (Andrew and Peter, 1980).

Ayodeji (2005) investigated the nutrient composition and the effects of processing on cassava leaf anti-nutrients. Genetically improved varieties of cassava plants were subjected to different processing methods, including sun-drying (SND), oven-drying (OVD), steaming (STM), shredding(SHD) and steeping (STP) and a combination of these methods to deliberately reduce the high level of cyanogenic glucosides present in the leaves. A combination of SHD and SND (SHD+SND) seemed to be the most effective technique of reducing the cyanide content. Proximate/mineral composition of the items were also determined.

At the end of the studies, the result revealed that the leaves contained: crude protein 348.0 gkg^{-1} DM (range:332.0 - 363.0 gkg^{-1} DM); crude fibre 121.0 gkg^{-1} DM (range: 115.0 - 127.0 gkg^{-1} DM); ether extract 70.0gkg^{-1} DM (range: 63.0 - 75.0 gkg^{-1} DM) and ash 69.0 gkg^{-1} DM (range: 63.0 - 78.0 gkg^{-1} DM). The CLM protein content was high and comparable with some rich conventional protein sources of plant and animal origins used in monogastric feed formulation. The mineral content was high particularly Ca, Zn, Ni and K. The "cyanide scare" associated with acute intoxification when food substances rich in cyanide is ingested at high levels seemed to be obviated by a combination of processing methods (SHD+SND) (Ayodeji, 2005).

Experiments were conducted by Krisada *et al*. (2009) to study the cassava root fermentation by yeasts in order to enhance the nutritive value of their products (fresh pulp and chips). Products were analyzed for proximate composition, mineral composition, essential amino acids and anti-nutrient content. The result of the analysis showed that there were increases ($P < 0.01$) in protein (30.4% in cassava chip (CC) and 13.5% in fermented cassava root (FCR) and fat contents

(5.8% in CC and 3.0% in FCR). *S.cerevisiae* fermented cassava products had very low hydrocyanic acid (HCN) contents (CC, 0.5 mg kg^{-1} and FCR, 47.3 mg kg^{-1}). There was also a remarkable increase in lysine content in the fermented cassava chip (FCC). The best acceptable and organoleptic attributes (colour, texture and aroma) of enriched cassava chip were achieved after 132 h of bio-processing (Krisada *et al.*, 2009).

The effect of fermentation on the nutrient quality of cassava was investigated by Antai (1990). Chemical analysis revealed a general increase in ash, fibre and crude protein content of the fermented cassava mash, while the carbohydrate content showed a substantial decrease. The results of the chemical analysis indicated that fermentation resulted in a slight protein enrichment of the fermentated cassava mash. When active yeast cells were inoculated into the cassava mash before fermentation, The yeast cells grew and generated additional cell mass which was reflected in a higher content of crude protein in the fermented cassava mash (Antai, 1990).

2.1.2 Nutritional enhancement of cassava products by supplements

Sanni and Sobamiwa (2004) carried out investigations on two cassava cultivars which were fermented for 3 days with the incorporation of soybean residue or full-fat flour at 25% (w/w) to produce gari. The results of the investigation revealed that fortified samples from two of the three procedures used, in which soybean was added at different stages of the fermentation had the crude protein content of soybean-fortified gari to be 8 to 12% (w/w), much higher than the 1 to 2% (w/w) of the unfortified gari.

Osho (2003) investigated the processing and acceptability of a fortified cassava-based product (gari) with soybean derivatives (soybean paste and milk residue, i.e. okara) included in the

process with the hope of improving the nutrient density without impairing the organoleptic attributes of this product.The results obtained gave an improved gari with high acceptability.

The nutritious value of fufu-fermented cassava flour was improved through supplementation with 10, 20, 30 and 40% pigeon pea flour by Akoja and Mohammed (2011). They subjected the products to proximate composition with 100% cassava flour as control. The results showed that the pigeon pea Fufu flour contained 7.70% protein, 0.27% fat, 1.08% ash at 10% level of inclusion and this increased to 16.45, 0.54 and 1.24% for protein, fat and ash respectively at 40% level of inclusion. Meanwhile, the carbohydrate contents decreased from 90.28 to 80.81% at 10% and 40% inclusion of pigeon pea flour respectively. Pigeon pea is a source of quality and inexpensive protein of about 14 - 28.9% and an excellent source of Vitamin B. Therefore, Pigeon pea as one of the ideal source for protein supplementation of starchy foods has been proposed

Edem *et al.* (2001) supplemented gari or farinha with soy beans at 10 and 15% soy protein levels to produce “soy gari” and fed the test diets to a 35 day-old albino rats of Wistar strain for 10 days. It was observed that the rat increased in body weight compared with those not fed on this diet.The study concluded that the consumption of soy gari at 10% soy protein supplementation be promoted in gari-eating areas, to ameliorate the endemic problems of protein deficiency disorders.

Festus and Nouba (1995) carried out investigation on the improvement of the nutritional value of fermented cassava flour, by the addition of full-fat soya bean flour on its quality and acceptability. The results showed that protein content increased with increased proportion of soya bean flour. At a 10% level of substitution of cassava with full-fat soya bean flour, the protein content was about 7%. Eighty-four percent of participants rated the product good to

excellent in an acceptability test of fufu made from 10% soya substituted flour in West and East provinces of Cameroon. The study showed that adding some full-fat soya bean flour to fermented cassava flour resulted in considerable improvement in the flour protein content and other nutritional elements, such as iron, phosphorus, and gross energy. The adoption and use of this composite flour by populations in which cassava fufu is a staple food will likely contribute to reducing the prevalent protein malnutrition.

Ibanga and Oladele (2008) gave the proximate composition and consumer acceptability of an improved and enriched dumpling made from maize, soybeans and cassava.The result of the investigation revealed that masovita has higher crude protein (19.66%), crude fat (9.0%) and energy content (386.8 kilocalories/g) than the traditional dumpling flours and Semovita. It was also shown that masovita compares favorably ($P<0.05$) with Semovita and other flour meals in taste, consistency, flavor and overall acceptability. Cassava flour has the least protein and fat contents and is the least accepted.

Horace *et al.* (1982) analyzed the cassava-based products (bread, cookies, bammy, patties, fritters, dumplings and grits) which are quite popular in the Caribbean area and prepared from cassava flour to which was added either soybean flour, peanut grits or cheese whey. These enriched products were investigated for their content of protein and were tasted and scored by a panel consisting mainly of natives from high cassava-consuming areas. The results revealed that the protein-enriched products showed increases in protein content ranging from 5-27% and were all highly acceptable to the members of the taste panel as compared to products made from cassava flour alone (Horace *et al.*, 1982).

Uche *et al*. (2008) investigated the fortification of a low protein cassava meal, (gari), with protein extract from soyabean seeds. The enriched gari was found to contain 9.63% protein. The process of gari production did not significantly denature the protein content and no visible change in characteristic flavour, physical appearance and taste was noticed.

The physicochemical properties of 'gari', fortified with Soy-Melon protein supplements at different processing stages were studied by Oluwafemi *et al*. (2009). The stages of processing were: (i) before fermentation (wet-mix method), (ii) after fermentation/before toasting(soak-mix method) and (iii) after toasting (dry-mix method).The samples were subjected to Physico-chemical tests. Results showed that supplementation increased the protein, fat and ash contents and the pH values, while the hydrocyanic acid content and itratable acidity reduced generally. Supplementation increased the protein content from 2.61% to a range of 14.26 to 19.51%. The fat increased from 3.20% to a range of 10.20 to 15.80%; while the Ash content increased from 1.15% to a range of 1.68 to 2.25%. Hydrocyanic acid was reduced from 1.345 mg/ 100 g to a range of 0.672 mg/100 g to 1.248 mg/100 g in the supplemented products. The pH increased from 3.62 to a range of 3.86 to 4.94 with the sample from the soak-mix method having the highest pH. The iron content increased from 93.57 mg kg^{-1} to a range of 98.30 mg kg^{-1} to 108.90 mg kg^{-1}. The phosphorus also increased from 162.5 mg kg^{-1} to a range of 178.1 mg kg^{-1} to 494.1 mg kg^{-1} sample. There was a decrease in the swelling capacities in all the supplemented samples. There were slight increases in the packed and loosed bulk densities. The reconstitution indices reduced in the samples supplemented before toasting but increased in samples supplemented after toasting. The delay period increased from 30 sec for the control sample to a range of 120 to 140 sec for the supplemented products (Oluwafemi *et al*., 2009).

The study by Adepoju *et al*. (2010) on nutrient composition and effect of processing methods on nutrient retention and contribution of some diets prepared from cassava. The results showed that, crude protein, lipid, fibre and ash contents of fresh cassava roots were low (0.9, 0.3, 0.5 and 0.4 g/100 g respectively). Its mineral profile was: potassium 166.6, sodium 222.1, calcium 25.0, magnesium12.5, phosphorus 57.3, iron 1.7, and zinc 2.1 mg/100 g sample. The results further indicated that processing cassava roots into various products improved availability of nutrients such as protein (1.3 g in gari to 2.6 g in fufu and amala), ash (0.5 g in abacha to 2.6 g in eba), potassium (234.5 mg in three days fermented garri to 473.2 mg in two days fermented lafun), calcium (22.7 mg in eba to 67.3 mg in two days fermented lafun), iron (1.0 – 4.3 mg), zinc (2.5 – 6.7 mg), as well as their calories ($p < 0.05$). A 100 g portion of raw and processed cassava into amala, eba, fufu and abacha yielded 140.5, 289, 284, 312, and 358 kilocalories of energy respectively. Soaking fresh cassava for more than two days resulted in significant reduction in mineral content of prepared diets due to leaching (Adepoju *et al*., 2010). 100 g portion of various diets can contribute between 12.3 to 16.1% energy, 6 to 14% iron, and up to 28% zinc to % RDAs of consumers.

'Gari' is a major component of everyday diet in Nigeria providing about 283 calories/person/day. The amount of protein in daily diet is very limited thus gari fortified with soybean products offers the chance to supply a relatively cheap improved starch staple that can improve family nutrition (Osho, 2003). Osho (2003) processed cassava roots into gari using the conventional processing practice. Soybean derivatives (soybean paste and milk residue, i.e. okara) were included in the process with the hope of improving the nutrient density without impairing the organoleptic attributes of this product. Possible varietal differences in the effect of soybean inclusion were also investigated by Osho (2003) . A fixed ratio of (75:25) of cassava to soybean

derivatives was used in the product development. Whole soybean paste and soymilk residue were prepared from two seed batches – pure variety TGx 536-02D and a mixed seed bulk. Results indicated that protein content has been greatly enhanced and enjoyed general acceptability.

A high protein food (11 to 12% protein) patterned on Nigerian gari was developed from ground cassava tuber, acid whey powder, and soy concentrate (Okezie and Frank, 1981). Two products were formulated. Product 1 contained cassava mash (C), soy concentrate (S), and acid whey powder (W) and was named (CSW); product 2 contained single cell protein (SCP) of yeast grown on cassava hydrolysate which replaced the soy concentrate (CSCPW). The products were subjected to proximate analysis by Okezie and Frank (1981).The result showed that CSW contained moisture (7.45%), fat (0.45%), total protein (11.56%), soluble protein (0.76%) acid detergent fibre (ADF) (2.66%), neutral detergent fibre (NDF) (11.09) and ash (2.63%), while CSCPW showed moisture (6.03%), fat (3.07%), total protein (11.41%), ADF (1.44%), NDF (42.18) and ash (3.24%).

Amino acid profile of the acid whey-soy gari showed an improvement over that of the Food and Agriculture and World Health Organization's reference pattern. Flavor and texture of modified acid whey gari were comparable to traditional gari. A 2 to 4 day fermentation of the ground cassava tuber resulted in a characteristic tangy flavour of the product and a loss of more than 50% in hydrocyanic acid content (Okezie and Frank, 1981).

Blending cassava tapioca meal with coconut palm (*Cocos nucifera*), African oil bean (*Pentaclethra macrophylla*) and Jamaican nutmeg (*Monodora myristica*) to improve its nutritive value was carried out by Donatus (2001). The result of the investigation revealed that the protein value increased from 0.88% obtained from cassava without additive to 3.94%, 5.69% and 8.31%

observed in the tapioca flavoured with *Cocos nucifera, Pentaclethra macrophylla* and *Monodora myristica*, respectively. There was an improvement in the lipid content from 0.5% to 11%, 19% and 27.50% in the cassava tapioca flavored with *P. macrophylla, C. nucifera* and *M. myristica* respectively. These additives also improved the mineral composition of cassava tapioca meal with macroelements such as calcium, potassium and phosphorus being present in acceptable quantity.

2.2 Effects of Processing on the Anti-nutritional Components of Cassava and the By-Products

2.2.1 Effects of processing on the cyanide level

Fermention was shown to be important in reducing cyanogenic glycosides and lowering of pH. Drying, grinding and cooking associated with cassava flour products are effective in detoxifying the bitter varieties (Montagnac *et al.,* 2009). Traditional processing and cooking methods for cassava can, if efficiently carried out, reduce the cyanide content to non-toxic levels and increase their palatability.The specific effects of various processing techniques on the cyanide content of cassava are known to have far reaching effects in reducing the anti-nutritional components (Montagnac *et al.*, 2009).

Societies which traditionally eat cassava generally understand that some processing techniques (soaking, cooking, fermentation etc.) are necessary to avoid getting sick. However, consumption of insufficiently processed bitter cassava may cause konzo (also called mantakassa), a paralytic neurological disease. A safe processing method, reportedly developed by Montagnac *et al.* (2009) was to mix cassava flour with water into a thick paste and then allowed to stand in the

shade for five hours in a thin layer spread over a basket. In that time about 5/6 of the cyanogenic glycosides are broken down by the linamarase; the resulting hydrogen cyanide escapes to the atmosphere, making the flour safe for consumption the same evening.

According to Tewe (1992), it has been shown that the higher the retention of starch in grated cassava the better the detoxification process. This could be attributed to the fermentative substrate provided by the starch. Also, the longer the fermentaion process the lower the residual cyanide content. (Tewe/FAO, 1992). The liberated cyanide will dissolve in the water when fermentation is effected by prolonged soaking, and will evaporate when the fermented cassava is dried.

Fermentation in water appears a more efficient method for reducing the cyanide of roots. For example, this process reduced cyanide by 70 - 95 percent of the original level after the roots were soaked in water for 3 days (Tewe/FAO, 1992). Gari obtained through the processing procedures involving grating and/or fermentation showed 80 - 90 percent reduction in total cyanide content relative to freshly peeled roots (Hahn,1992). He reported HCN content of 1.9 mg/100 g for gari, 2.5 mg/100 g for fufu (Nigeria) and 1.0 mg/100 g for fufu (Zaire) or lafun (Nigeria). HCN concentration in 202 gari samples collected across the cassava growing areas of Nigeria had 0-3.2 mg/100 g with a mean of 0.6 mg/100 g (Hahn, 1992).

Cyanide elimination by sun-drying on a concrete floor, compared to that by oven-drying at 60°C was studied by Guillermo and Mauricio (2006). Sun-drying was found to eliminate more cyanide than oven-drying (82 to 94% versus 68 to 76% respectively) and in addition, most of the cyanide in sun-dried foliage was shown to be free cyanide (62 to 77%), whereas only 24 to 36% was found in oven-dried foliage.

Tewe/FAO (1992) reported the development of a combined acid hydrolysis and fermentation process at FIIRO (Federal Institute for Industrial Research, Oshodi, Nigeria) and there was an achievement of a 98% reduction in total cyanide after dehydration of the cassava flour for use in the feeding of chickens. It was revealed that since cassava root contains about 61% water, coupled with the solubility of its cyanogenic glucoside component, the dehydration (dewatering) process results in a substantial reduction in the content of this toxin in the pressed pulp.

Sun-drying is cost effective, but slow and often encourages the growth of mould and other micro organisms including *Aspergillus flavus* (pathogenic), *A. fumigates, A.cherahen, A. teirenus, A.flaripes, A. japonicas, A. niger, A. ochracuss and Penicillium rubrum*. This microbial growth can expose the consuming animal to aflatoxicosis and/or mycotoxic infection. Also, cyanide will not be completely liberated and the enzyme will be destroyed during drying (Tewe/FAO, 1992; FAO, 1990).

Simple boiling of fresh root pieces was found not to be always reliable, since the cyanide may be only partially liberated, but the free cyanide of cassava chips is rapidly lost in boiling water. About 90% of free cyanide was shown to have been removed within 15 minutes of boiling fresh cassava chips, compared to a 55% reduction in bound cyanide after 25 minutes (Tewe/FAO, 1992; Hahn, 1992). Soaking in water improves detoxification as cells are broken by osmosis and fermentation, which facilitates hydrolysis of the glycosides. Short soaking (four hours) is ineffective, but when longer periods are used (18 to 24 hours) cyanide levels can be reduced by 50 percent. Squeezing the product has been identified as a fundamental step in the elimination of the soluble cyanides (Tewe/FAO, 1992).

Generally the cassava peel was shown to contain higher cyanide content than the pulp. Removal of the peels therefore reduces the cyanogenic glucoside content considerably. In the studies carried out by Tewe/FAO (1992), the peel of the “bitter” cassava variety was shown to contain an average of 650 ppm and the pulp to contain 310 ppm total cyanide; the corresponding values for “sweet” varieties were 200 ppm and 38 ppm respectively (FAO, 1990).

Paula *et al*. (2005) pointed out that the so-called "sweet" cassava types were known to be probably eaten raw or lightly boiled without harm. The "bitter" forms are traditionally processed by one or a combination of operations of peeling, grating, fermenting, dehydrating, sun drying, frying or boiling. Hence, for example, fermentation before processing into products such as chikwangue or fufu eliminates almost all total and free HCN (Kumar, 1992). Post-harvest wilting of cyanogenic leaves may reduce the risk of cyanide toxicity. While most processes rely on enzymatic hydrolysis to reduce the glycoside concentration. In practice, the extent of glycoside breakdown is mainly controlled by fermentation time (Kumar, 1992; Paula *et al*., 2005).

The amount of total HCN was known to have been reduced by 83% to 96% in such products as gari and attieke for which the cassava roots are peeled and grated before processing (FAO, 1990). The type of processing technique used was shown to determine the level of cyanide removal. Processing methods used to produce farinha in Brazil and gari in West Africa have reduced the total cyanide content to less than one eighth of that using heap fermentation and less than one sixteenth of that using sun drying (Paula *et al*., 2005).

Onyesom *et al.* (2008) gave clear evidence of detoxification of cassava products through fermentation with varying amounts (1.0, 2.0, 3.0, 4.0 and 5.0 g) of lemon grass (*Cymbopogon*

citratus) for one to five days. Fermentation resulted in a decrease in the cyanide content and this was significant ($P < 0.001$) by the 5th day in all the treatments.

Detoxification of cassava cultivars (30572 TMS and 30555 TMS) during their traditional methods of processing to produce gari and cassava flour was investigated by Kemdirim *et al*. (1995). The result indicated that fermentation of cassava pulp for 96 hours during cassava processing of gari was shown to reduce the HCN by 22 ppm (52.4 percent) and 20 ppm (57.3 percent) for 30572 TMS and 30555 TMS respectively. Soaking of the sliced cassava tissue for 24 hours in cassava flour production prior to sun drying resulted in 16 ppm (38.1 percent) and 15 ppm (38.4 percent) HCN reduction for 30572 TMS and 30555 TMS respectively. HCN loss during sun-drying was 6 ppm (14.3 percent) and 5 ppm (12.8 percent) for the two cultivars. There was a significantly ($P < 0.05$) higher HCN loss in processing of gari than cassava flour. The residual cyanide in gari was 12 ppm for 30572 TMS and 10 ppm for 30555 TMS and that in the flour was 20 ppm for 30572 TMS and 19 ppm for 30555 TMS (Kemdirim *et al*., 1995).

Oboh *et al*. (2002) investigated the suitability of pure strain of *Aspergillus niger* when added to cassava pulp and fermented for 72 h to be processed to gari and flour, the forms in which cassava products are popularly consumed in Nigeria.The result of the investigation indicated that there was a decrease in the level of cyanide content in the *Aspergillus niger*-fermented cassava products [flour (9.1±0.2 mg/kg), gari (4.1±0.2 mg/kg)] (Oboh *et al*., 2002).

Another evaluation of the effects of fermentation of cassava products on cyanide content was carried out by Muzanila (2000).Total cyanide decreased from 89 ppmHCN to 18.1 ppm HCN (80% reduction). Free cyanide decreased from 8.71 ppm HCN to 6.22 ppm HCN (29% reduction). The intermediate cyanide increased from 10.2 ppm HCN to 12.31 ppm HCN (21%

increase). Leaves of two varieties of cassava subjected to African household processing (heat treatment, pounding, cooking and crushing, grinding and cooking) by Aduni *et al*. (2008) showed reduction in cyanogenic potential (> 99% reduction). However, Awoyinka *et al*. (1995) showed that blanching made HCN potential unchanged.

Ravindran (1992) demonstrated that simple sun-drying alone eliminated almost 90% of the initial cyanide content as indicated earlier by Guillermo and Mauricio (2006) earlier. But when combined with chopping and wilting, cyanide in the dried meal was reduced to levels which are safer for monogastric animals (Ravindran, 1992). The values obtained for 0, 1, 2, and 3 wilting (days) were 173, 141, 114 and 93 for full leaves and 109, 88, 72 and 53 for chopped leaves respectively.

Drying the leaves has been shown to also reduce HCN content (Lekule and Sarwatt 1992). A reported HCN content of 1210 ppm of DM for fresh leaves and 30 ppm for dried leaves was made.

Sokaria and Kariboa (1992) investigated grated cassava to which tap water was added at levels of 25%, 50% and 75% (v/w) held at 30°C, 40°C or 50°C and examined over a 6 h period for cyanide content.It was found that during the come-up time, i.e. the time between addition of water and attainment of desired holding temperature (between 14 and 47 min), reductions in bound cyanide of 54-85% occurred, depending on the level of added water and holding temperature. The result further indicated that the corresponding losses for the control samples, to which no water was added, were 25 - 33%. The biggest reduction in the bound cyanide of > 99% (from 89.0 to 0-6 ppm) occurred in grated cassava with 75% added water held at 50°C.

Okafor (2004) assessed the cyanide overload of 40 cassava (gari) processing workers, 25 frequent consumers of cassava foods and 20 cigarette smokers (all Nigerians) using a new simple kit method for determination of thiocyanate (cyanide metabolite) in urine. The resultsof the findings revealed that the mean thiocyanate measured in the urine of three groups of cassava processing workers were 9.48 ± 2.8, 8.70 ± 2.23, and 7.46 ± 2.57 ppm. The mean thiocyanate measured in the urine of frequent cassava consumers and cigarette smokers were 3.57±0.6 and 13.99±13.81 ppm, respectively. The urine samples of 15% of the processing workers measured 10 ppm SCN (172 μmol/L), while two urine samples from the smokers measured 30, and 44 ppm SCN. The cyanide contents of some cassava based foods commonly consumed among Nigerians (obtained from Ogbomosho and Owelli-Agwu markets in Nigeria) were determined and ranged from 0.68±0.31 to 0.88±0.21 for total cyanide and 0.14±0.03 to 0.52±01 mg CN/100 g DM for free cyanide. The high level of urine thiocyanate was believed to have resulted from inhalation and skin absorption of hydrocyanic acid during processing as well as ingestion of cassava foods. Absorbed from the skin or readily inhaled during roasting of gari or from cigarette smoking, hydrogen cyanide passes through the lungs into the blood stream and is converted to SCN in the liver and kidneys (Okafor, 2004).

A wetting method has been proven to reduce the cyanide content of cassava flour by up to 5/6. and has recently been successfully field tested by rural women in Mozambique (DDCN, 2008). It can be assumed that drying would substantially reduce the amount of HCN liberated, as has been observed for the sliced roots reported in the literatures (DDCN, 2008).

Adegola and Asaolu (1980) observed that the reduction in HCN level will probably only take place with slow drying, since drying at higher temperatures has been proved to be less efficient.

Eddy *et al*.(2007) established that at the high temperature required for baking, cyanides are easily gotten rid off the flour.

Detoxification of cyanogenic glucosides from cassava products was enhanced in gari by the research work of Ogbo *et al.* (2009). This was achieved by using biomass contained in dregs of palm wine to innoculate cassava mash just before dewatering and fermentation. The results indicated reduced cyanide content.

A similar study undertaken by Agbo-Egbe *et al.* (1995) to investigate the effectiveness of village processing techniques in reducing cyanogens to very low levels in Cameroonian cassava based food, "miando". 'Miando' is prepared by soaking the unpeeled cassava root. Soaking and fermentation of the roots do facilitate contact between the endogenous enzyme, linamarase and the cyanogenic glucoside substrate. This would be followed by mashing/peeling, to remove peels, central fibers and excess water. The product is then milled, packaged into cylindrical shapes with long leaves and boiled for some minutes to get ready for consumption as Miando (Agbo-Egbe *et al.,* 1995).

The sub-processes used in the production of miondo were highly effective in reducing the total cyanogen content of the freshly harvested and unpeeled cassava root (396.2 - 512.0 mg HCN Kg^{-1}) to very low levels in the final product (1.4 - 2.8 mg HCN kg^{-1}) ready for consumption ; this accounted for a mean overall reduction in total cyanogens of 99.5 % (range 99.3-99.6%). The most important stages in the production of miondo, with regard to cyanogen reduction, were the soaking, mashing and dewatering sub-processes (Agbo-Egbe *et al*., 1995).

Agbo-Egbe *et al.* (1995) reported that softening occurred only after three days of soaking the whole unpeeled cassava roots. Fermentation of cassava roots has been attributed to lactic acid bacteria while root tissue softening has been associated with an increase in the activity of some cell wall degrading enzymes such as polygalacturonase, pectinase and cellulase (Agbo-Egbe *et al*., 1995).

Zoë *et al*. (1998) compared the effectivness of processing methods on the cyanide detoxification of the cassava products. Crushing cassava root pieces prior to drying was found to significantly improve the efficiency of cyanogen removal by, on average, 22% during laboratory experiments and 12% during field trials. The crushing procedure was optimized and a low cost prototype crusher developed. A reduction in the processing time resulted from crushing the root disks prior to drying. The processing method involving crushing was ranked second in terms of efficiency of cyanogen removal in a comparative study with sun-dry processing methods, that are commonly used in East Africa (Zoë *et al*., 1998). Pounding cassava to small pieces in a traditional pestle and mortar prior to drying was the most efficient, providing 90% removal of cyanogens. Pounding and crushing cassava prior to sun-drying were significantly better than all other root preparation pre-treatments evaluated

The effect of six individual strains of the dominant microflora in solid substrate fermenting cassava on cyanogen levels was examined by Alexander *et al*. (1995) . Six out of eight batches of disinfected cassava root pieces were incubated for 72 h after inoculation with either of the fungi *Geotrichum candidum, Mucor racemosus, Neurospora sitophila, Rhizopus oryzae* and *Rhizopus stolonifer,* or a *Bacillus sp.,* isolated from on-farm fermented cassava flours from Uganda. One non-inoculated batch was incubated as a reference. Levels of the initial and final

moisture and cyanogens were then assayed (Alexander *et al.*, 1995). The result indicated that incubation of disinfected root pieces reduced cyanogenic glucoside levels significantly to 62.7% of the initial value. Microbial growth resulted in significant additional reduction of the cyanogenic glucoside levels to 29.8% of the levels which were obtained after non-inoculated incubation. Among the tested strains, *N. sitophila* reduced cyanogenic glucoside levels most effectively, followed by *R. stolonifer* and *R. oryzae*. Of all the fermented samples, *Rhizopus spp*. showed the highest proportion of residual cyanogens in the cyanohydrin form (Alexander *et al.*, 1995).

The cyanide content of fresh whole-root chips of two cassava varieties (CM -40, low-cyanide, and CMC-84, (high-cyanide) as affected by plant age (9 – 12 months) was determined monthly. The effect of sun-drying, either on concrete floors (plain or black-painted) or on inclined trays, on cyanide elimination was studied by Guillermo *et al.* (1984). The results indicated that total cyanide contents in fresh chips of variety CMC-84 were always higher (772 ± 167 versus. 436 ± 111 mg/kg DM) than those of variety CMC-40, and in both varieties cyanide contents in chips decreased as plant age increased. Most of the cyanide in fresh chips was found as bound cyanide (66% for CMC-40 and 79% for CMC-84), but the proportion of free cyanide was higher than values previously determined in the separate root tissues. Sun-drying on inclined trays normally required less time than on a concrete floor; at the fresh chip loading rate used (8.5–9.0 kg m−2) for floor drying, no appreciable differences in drying times and cyanide elimination were found between plain and black-painted concrete surfaces. Sun-drying on a concrete floor eliminated more cyanide (86 – 93% of initial level), for both varieties, than on inclined trays (6 1– 87%). Most of the remaining cyanide in chips dried on a concrete floor was found as free cyanide (62 ±

16% for CMC-40 and 59 ± 18% for CMC-84), but in chips dried on trays these values were considerably lower (25 ± 11% for CMC-40 and 19 ± 8% for CMC-84) (Guillermo *et al.,* 1984).

Ganiyu (2006) investigated the effects of fermentation on the detoxification of cassava peels using a mixed culture of *Saccharomyces cerevisae* and two bacteria namely *Lactobacillus delbruckii* and *Lactobacillus coryneformis*.The cassava pulp were fermented with pure strains of microorganisms for 3 days. The squeezed liquid from the fermented pulp was used to ferment the cassava peels for 7 days. Analysis of the dried fermented peels revealed that the treatment brought about a significant ($P < 0.05$) decrease in the cyanide (6.2 mg/kg) and phytate content (789.7 mg/100g) when compared with the unfermented cassava peels, which had 44.6 mg/kg cyanide and 1043.6 mg/100g phytate(Ganiyu, 2006). These values can also be compared with the cassava peels fermented with waste water from the naturally fermented cassava pulp that had 23.5 mg/kg cyanide content. The cyanide concentration in the cassava peels fermented with waste-water from fermented cassava pulp was low, when compared with the usual cyanide content of cassava products in Nigeria [19.0 mg/kg (gari), 25 mg/kg (fufu)], and that of the cyanide content of some micro-fungi fermented cassava products (9.1 - 17.2 mg/kg). This showed that the microorganisms in the waste water were capable of partially degrading cyanogenic glucosides and the breakdown products (Ganiyu, 2006).

Essers *et al.* (1995) described the processing of cassava roots by the Alur tribe in Uganda to include a stage of solid substrate fermentation in heaps. In determining changes in cyanogen levels during the process in the flour samples from rural households, Essers *et al*. (1995) found that mean (± SD) total cyanogen levels in flour collected were 20.3 (± 16.8) mg CN equivalents kg^{-1} dry weight in 1990 and 65.7 (± 56.7) in 1992. Mean (± SD) levels of cyanohydrins plus

HCN were 9.1 (± 8.7) in the 1992 flour. Total cyanogen levels in the village monitored were reduced considerably by heap-fermentation from 436.3 (± 140.7) to 20.4 (± 14.0) mg CN equivalents kg^{-1} dry weight cassava. Heap-fermentation was significantly more effective in reducing cyanogen levels than sun-drying alone, but did not always result in innocuous levels of cyanogens (Essers *et al.*, 1995).

Padmaja (1995) compared the efficiency of various traditional processing techniques practised in cassava production to reduce cyanide in tubers and leaves. Drying was shown to be the most ubiquitous processing operation in many tropical countries. Sun drying was shown to eliminate more cyanide than oven drying because of the prolonged contact time between linamarase and the glucosides in sun drying. Soaking followed by boiling has proven better than soaking or boiling alone in removing cyanide. A 80 to 95% cyanide loss occured during the various stages of gari manufacture. The best processing method for the use of cassava leaves as human food is shown to be pounding the leaves and cooking the mash in water. Fermentation, boiling, and ensiling are efficient techniques for removing cyanide from cassava peels (Padmaja 1995).

The most effective commercial method to eliminate partial or total cyanogenic acid content of cassava is based on the controlled action of heat. Temperatures between 40 and 80 ^{o}C are effective in eliminating the largest portion of the free cyanogenic acid (Julian *et al.*,2001).

The natural dehydration with solar rays is also a secure system to destroy the cyanogenic acid without affecting the action of linamarase enzyme (Julian *et al.*, 2001). This is also in line with the findings of Padmaja (1995).

Alain *et al.* (1996) investigated the overall kinetics of retting, a spontaneous fermentation of cassava roots performed in central Africa, in terms of microbial-population evolution and biochemical and physicochemical parameters. It was established that endogenous cyanogens were almost totally degraded during the traditional process. Cyanide compounds responsible for the toxicity of cassava roots were assayed throughout the process. Linamarin, the main cyanogenic glycoside, was highly degraded (95%) after 4 days of retting. An appreciable decrease in cyanogen content was found after 2 days of fermentation, which could be attributed to the pH decrease within the roots. The residual cyanogen in the last stage of retting (50 μg/g) was almost entirely in the form of cyanohydrin or free cyanide (Alain *et al.*, 1996).

The effect of different cooking times and steeping times on the cyanide content, colour and flavour of cassava slices were evaluated by Christian (2009). The evaluation of the slices were carried out under different cooking times (20 minutes, 30 minutes, 40 minutes, 50 minutes, 60 minutes) and steeping times (12 hours, 15 hours, 18 hours, 21 hours, 24 hours). Increasing the cooking and steeping times reduced cyanide content. It was suggested that 40 minutes and 18 hours of cooking and steeping respectively, were the optimum cooking and steeping times.

A 90% reduction of free cyanide and a 55% reduction of bound cyanide resulted by the cooking of cassava (Christian, 2009). However, previous workers had shown that soaking cassava in water removes about 20% of free cyanide while bound cyanide is only negligibly reduced (Christian, 2009).

The removal of cyanogens from cassava roots during sun-drying indicated that linamarin levels in sun-drying cassava root pieces decreased exponentially paralleled with the moisture loss, and stabilized when moisture levels reached about 15%. Linamarin degradation in thin root segments

was found to be significantly slower and less complete than in thick ones. Disinfected longitudinal root halves, oven-dried at 40 °C for 24 h, were shown to have significantly higher residual linamarin levels than the matched ones subjected to humid incubation at 25°C (Alexander *et al.,* 1996).

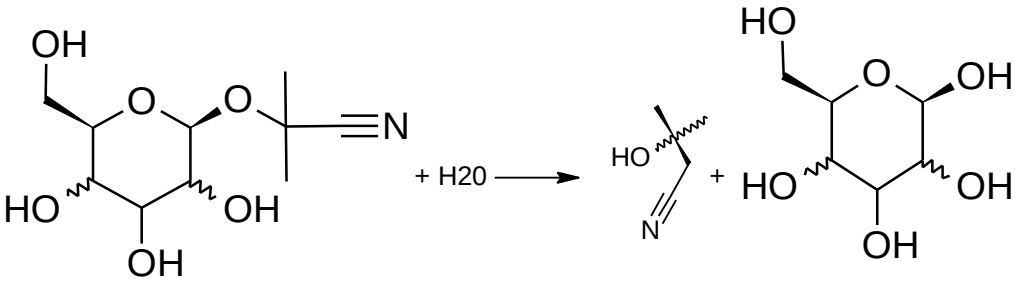
Emmanuel (1983) studied the degradation of cyanogenic glycosides in spontaneously fermenting cassava root pulp and in fresh pulp samples pretreated to prevent either endogenous β-glycosidase activity, fermentation, or both. The results suggested that the contribution of the fermentation process in cyanide detoxification of pulped cassava roots is minimal.

Fifty cassava flour samples from Mogincual District of Nampula Province in Mozambique were found to contain, on average, 43 mg HCN equivalents/kg flour (ppm), of total cyanide, which is typical for a year of average rainfall (Arnaldo *et al.,* 2007). Five gram samples of the 30 flour samples of highest cyanide content were mixed with water and left for 5 h at 30°C and it was found that the mean% retention of cyanide was 16.7%. Using 500g instead of 5 g samples caused an increase in the % retention due to accumulation of the very weak acid, HCN, in the damp flour mass, which also decreased its pH and somewhat reduced the rate of breakdown of linamarin catalysed by linamarase. This problem was overcome by spreading out the damp flour in an approximately 0.5 cm thick layer on a tray, which allowed the release of HCN (Arnaldo *et al.,* 2007).

If the wetting/spreading method is acceptable to users it could greatly reduce the cyanide intake of the population of eastern, southern and central Africa and has the potential to eliminate konzo from Africa (Arnaldo *et al.,* 2007).

Ajaelu *et al*. (2008) employed an improved method of analysis of cyanide in cassava and cassava products using methemoglobin complex. By this, the cyanogen content of cassava mash, pre-fufu mash, fufu and gari was determined spectrophotometrically. The result of the investigations indicated that the average cyanogen content obtained were 14.68 ± 0.66, 13.49 ± 0.02, 11.94 ± 0.02 and 9.87 ± 0.64 mg/kg for cassava mash, pre-fufu, fufu and gari, respectively. The values estimated were found to be greater than the WHO safe value for cassava flour (10 mg/kg).

A simple wetting method developed by Howard (2009) had proved to reduce total cyanide content of cassava flour 3-6 fold. The method involved spreading wet flour in a thin layer and standing in the shade for five hours to allow evolution of HCN gas. It was found that breakdown of linamarin catalysed by linamarase to acetone cyanohydrin, followed by its spontaneous decomposition to HCN and acetone was greatly increased by standing the wet flour in the sun. Treatment for two hours in the sun gave the same amount of total cyanide remaining as five hours in the shade (Howard, 2009). This rapid treatment in the sun may be more acceptable to rural women in Democratic Republic of Congo, than five hours in the shade. The two methods are offered as alternatives for use in rural Africa. With adequate linamarase present the residual cyanogen remaining after the wetting treatment was acetone cyanohydrins (Howard, 2009).



linamarin cyanohydrin β-D-glucose

Figure 2.1: Hydrolysis of linamarin

Howard (2006) thoroughly mixed ten samples of cassava flour from Mozambique, Indonesia and Australia and one sample of gari from Mozambique with water in the ratio 1:1.25. All the water was seen to have been absorbed by the flour and the mixture was left in an open beaker at 30 °C. It was found that, provided that there was a reasonable amount of linamarase in the flour, the total cyanide content reduced about three-fold over 5 h. Addition of exogenous linamarase increased greatly the rate of breakdown of linamarin in the flour. There was no breakdown of linamarin from a gari sample at pH 4.2, but breakdown occurred when the pH was increased to 6 with buffer.

Cassava samples processed by wet fermentation, solid-state fermentation and sun-drying were analysed for residual cyanogens and the presence of mycotoxins by Muzanila *et al.* (2000). Wet fermentation was very effective in reducing cyanogen content in bitter varieties. The total cyanogen content of 5.84 mg HCN kg^{-1} was less than that for samples processed by solid-state fermentation which had a residual cyanogens content of 14.0 mg HCN kg^{-1}. Sun-dried cassava samples (sweet varieties) had 6.8 mg HCN kg^{-1}.

Julien *et al*. (2008) utilised different processing techniques to remove cyanogens and found that their effectiveness depends on the processing steps and the sequence utilized, and it is often time-dependent. Pounding or crushing is known to be the most effective for cyanogenic glucoside removal because it ruptures cell compartments, thus allowing direct contact between linamarin and the enzyme linamarase that catalyzes the hydrolytic breakdown (Julien *et al.,* 2008). Crushing and sun-drying cassava roots made into flour was shown to remove 96% to 99% of total cyanogens, whereas soaking and sun-drying into lafun or fufu, or soaking and fermenting and roasting into gari or farinha, have been able to remove about 98% of cyanogens. For cassava leaves, which have 10 times more cyanogens than roots, pounding and boiling in water is proven to be an efficient process to remove about 99% of cyanogens. Other strategies known to reduce toxicity include development of low-cyanogen cassava varieties and cassava transgenic lines with accelerated cyanogenesis during processing.

Iodine Deficiency Disorders (IDD) in two areas in the Western and Central parts of Central African Republic (CAR) revealed that cassava roots were consumed daily in all interviewed households. Iodine-excretion was low in both areas studied but total goitre rate was 28% in the central area and 50% in the western area. The thorough traditional processing-method strictly adhered to in the central study area effectively removed cyanogens as indicated by low urinary thiocyanate. Frequent shortcuts in processing in the western area resulted in cyanide exposure as indicated by urinary thiocyanate levels three times higher (Peterson *et al.*, 1995) .

Transgenic cassava plants with a 92% reduction in cyanogenic glucoside content in tubers and acyanogenic (<1% of wild type) leaves were obtained by RNA interference to block expression of CYP79D1 and CYP79D2, the two paralogous genes encoding the first committed enzymes in

linamarin and lotaustralin synthesis (Kristen *et al*., 2005). About 180 independent lines with acyanogenic (<1% of wild type) leaves were obtained. Only a few of these were depleted with respect to cyanogenic glucoside content in tubers. The investigation demonstrated that it is possible to drastically reduce the linamarin and lotaustralin content in cassava tubers by blockage of cyanogenic glucoside synthesis in leaves and petioles. The reduced flux to the roots of reduced nitrogen in the form of cyanogenic glucosides did not prevent tuber formation (Kristen *et al.,* 2005) . In this study, results had it that transgenic cassava plants with > 99% reduction in cyanide potential were obtained in leaves and a 92% reduction in tubers using RNA interference (RNAi) technology (Kristen *et al.,* 2005) .

Asegbeloyin and Onyimonyi (2007) determined the effect of different processing methods on the cyanide and residual cyanide content of gari using gari from bitter variety of cassava. The processing methods investigated were the unfermented with oil, the unfermented without oil, the fermented with oil and the fermented without oil. The reference cyanide content of the cassava pulp determined immediately after grating was found to be 437.4 ± 15.2mg/kg.The crude protein content of the fermented groups (treatments 3 and 4) were higher in the the two treatments than those of the unfermented groups (the first two treatments). The addition of palm oil was shown to increase the ether extract values of the groups with palm oil. Fermentation was found to have a significant effect ($P < 0.01$) on the cyanide content of the gari. Cyanide content of the treatments at "garification" were 223.29 ± 6.2; 203.16 ± 11.7; 91.78±8.4 and 99.34 ± 8.9mg/kg for the respective treatments. The effect of palm oil addition on the cyanide content was not significant ($P > 0.05$). The residual cyanide content of the treatments after one week (7 days) of storage were 31.42 ± 9.2; 33.6 ± 2.6; 25.2 ± 2.8 and 25.8 ± 1.6 mg/kg for the respective treatments. These values were not significantly different ($P > 0.05$). It was concluded that fermentation was

a veritable tool in gari production. Storage of gari for upward of 7 days further provides an enabling condition for the detoxification of cyanide from unfermented groups to safe levels (Asegbeloyin and Onyimonyi, 2007)

500 random samples of gari (a cassava by-product) being hawked for sale in Ibadan markets, in Nigeria, were assayed for hydrocyanic acid (HCN) content. Most of the samples contained detectable amounts of HCN, ranging between 0.8 and 38 mg/kg, and only a very small proportion (0.4%) contained no cyanide. The limit of HCN detection was 0.1 ppm. There was no significant difference ($P < 0.01$) between the mean total cyanide (glycoside-bound plus non-glycosidic) and free cyanide (non-glycosidic) contents, 8.0 ± 6.9 mg HCN/kg and 7.2 ± 5.8 mg HCN/kg, respectively; indicating that an overwhelming proportion of the residual cyanide content of commercial gari could be present in the "free" form (Emmanuel, 2002).

A survey was undertaken by Adindu *et al.* (2003) to determine the cyanogenic potential of three important ready-to-eat (RTE) cassava products (garri, fufu and tapioca) displayed for sale in Port Harcourt markets. The survey that lasted 3 months, showed that the mean total cyanogen content of the test samples was 25.4±5.0, 20.0±6.0 and 17.5±6.2 mg/kg sample for garri, fufu and tapioca, respectively. The mean total cyanogen levels for all the samples were higher than the FAO/WHO safe level for cassava flour (10 mg/kg). The implication of the findings was that consumers of these improperly detoxified products in the locality may be exposed to health problems through intake of cyanide (Adindu *et al*., 2003).

Leaves of 3 genetically improved varieties of cassava plants were harvested and subjected to different processing methods including sun-drying (SND), oven-drying (OVD), steaming (STM), shredding (SHD) and steeping (STP) and a combination of these methods to deliberately reduce

the high level of cyanogenic glucosides present in the leaves (Ayodeji, 2005). A combination of SHD and SND (SHD+SND) seemed to be the most effective technique of reducing the cyanide content. Particular attention was paid into the determination of hydrocyanic acid (HCN), polyphenols (tannic acid) and phytic acid as they constitute the major anti-nutrients militating against the utilization of cassava leaf in animal nutrition (Ayodeji, 2005). The leaves contained: crude protein 348.0 gkg^{-1} DM (range: 332.0 - 363.0 gkg^{-1} DM); crude fibre 121.0 gkg^{-1} DM (range: 115.0 - 127.0 gkg^{-1} DM); ether extract 70.0 gkg^{-1} DM (range: 63.0 - 75.0 gkg^{-1} DM); ash 69.0 gkg^{-1} DM (range: 63.0 - 78.0 gkg^{-1} DM) and gross energy 47.0 $MJkg^{-1}$ (range: 46.5 - 47.2 $MJkg^{-1}$). The CLM protein content was high and comparable with some rich conventional protein sources of plant and animal origins used in monogastric feed formulation. The mineral, Ca, Zn, Ni and K are particularly high. The "cyanide scare" associated with acute intoxification when food substances rich in cyanide is ingested at high levels seemed to be obviated by a combination of processing methods (SHD+SND) (Ayodeji, (2005)).

A reciprocal relationship was observed between the cyanide content of gari and particle size. Hydrocyanic acid (HCN) content was positively correlated ($r = 0.62$) with sugar content but the correlation with starch content was poor ($r = 0.33$). Therefore, it appears that larger particles size in gari is beneficial (Emmanuel and Mike, (1980).

The effects of dice size, fermentation time, blanching time and drying temperature on the total cyanide content and swelling capacity of gari samples produced by the steam gelatinization technique were analysed by Ajibola *et al.* (1987).Gari produced from 1 cm cubes of cassava roots, fermented for 3 days, blanched for 10 minutes and dried at 55°C had a total cyanide

content lower than those of gari produced by the conventional technique. The swelling capacity was also better (Ajibola *et al*., 1987).

Maduagwu and Oben (2007) compared the extent of the loss of hydrocyanic acid (HCN) from grated cassava roots, selected from both the sweet and bitter varieties, in the roasted grit (gari) derived from their fresh pulp which had been dewatered and fermented by two different processes; the quick (1-day) 'screw press' method (QSP) and the slow (3-day) traditional one (STD), respectively. The relative amounts of HCN which had disappeared after 1 day, in the case of QSP, and 3 days, in respect of STD, were comparable (92 – 100%) for either free (non-glycosidic) or bound (glycosidic) cyanide content of the two cultivars, indicating that the former method was more efficient than the latter in the detoxification of the grated pulp. The QSP method appeared to retain some of the bound cyanide while with the STD method, virtually no bound cyanide was detectable. About 83 – 91% of the total HCN content of the grated roots was present as free cyanide. It would seem that varietal differences in HCN contents of cassava may not be a critical factor in the preferential selection of the roots for 'garification.

Hang and Preston (2005) investigated the HCN content together with some other compositions in leaves and discovered that HCN can be reduced by sun-drying and ensiling. The use of simpler methods of processing the fresh leaves, such as chopping, washing and / or wilting would facilitate the use of cassava leaves as animal feed.

The composition of the leaves of twenty cassava varieties, taken from the upper part of the plant at the time of root harvesting, ranged from 23.7 to 31.1% for DM, 23.7 to 29.5% for crude protein (in DM) and 610 to 1840 for HCN (mg/kg DM). Leaves collected from a high-yielding variety after 60 days of growth and at root harvest (180 days) were wilted for 24 hours for

determination of changes in the DM and HCN content. The HCN level was reduced by 58% after 24 hours with no difference between the two sources of leaves. The cyanide levels in leaves are influenced by genetic, physiological, edaphic and climatic differences with the stage of maturity being perhaps the major source of variation (Hang and Preston, 2005).

Uyoh *et al.* (2009) investigated the effects of two fermentation methods (fixed and unfixed) on the HCN content, texture, colour, flavour, water retention capacity and bulk density of "fufu", a cassava based entree using an improved cassava cultivar, TMS 0635 The HCN content of fufu from fixed fermentation method was significantly lower ($p<0.001$) than that from unfixed fermentation. On the other hand, bulk density and water retention capacity were significantly higher ($p < 0.001$) in fufu processed from fixed fermentation method. Texture, colour and flavour were, however, not significantly different ($p>0.05$) in fufu processed from the two methods. The fixed fermentation method is, therefore, recommended for fufu processing with cassava cultivar TMS 0635 (Uyoh *et al*,. 2009).

In his effort to determine chages in some chemical constituents during the fermentation of cassava tubers, Augustine (1980) analysed the 'gari' and 'lafun' processed from fermentated cassava tuber. The result revealed that pH fell from 6·5 to 4·3 in the former. Titratable acidity increased during the course of fermentation. No cyanide residue was detected in gari by fluorimetry although low cyanide levels were detected in some samples of lafun. Thin layer chromatography (TLC) of extracts from gari confirmed the absence of cyanogenetic glycosides

2.2.2 Effects of processing on phytate level

Phytate (inositol hexakisphosphate) is a regulator of intracellular signaling and a form of phosphate storage in plant seeds, but it can bind proteins and minerals in the gastrointestinal tract preventing absorption and utilization by the body. Specifically, phytate interferes with the absorption of divalent metals, such as iron and zinc, which are essential nutrients. A recent trivariate analysis estimated total absorbed zinc as a function of total dietary zinc and phytate and concluded that the amount of phytate in the diet should be considered when determining zinc requirements (Davis *et al.,* 2009).

Generally speaking, phytate levels in the unprocessed foods were found to be 6.24 ± 0.22 mg of phytate/g of sample (cassava), 8.55 ± 0.45 mg/g (cocoyam), 6.37 ± 0.32 mg/g (yam), 7.34 ± 0.31 mg/g (white maize), 6.86 ± 0.12 mg/g (yellow maize), 8.86 ± 0.20 mg/g (red sorghum), 4.49 ± 0.22 mg/g (rice), 8.24 ± 0.22 mg/g (cowpea), and 6.88 ± 0.52 mg/g (soybean) (Emmanuel *et al*., 1990). Emmanuel *et al*. (1990) stated that seventy-two hours of fermentation substantially reduced phytate levels in them, ranging from 80% to 90% fo rice, cassava, and cocoyam and from 52% to 65% for sorghum, maize, soybean, cowpea, and yam. Lowering of phytate levels was most rapid within the first 48 hrs of fermentation. Cooking had little reducing effect on phytate levels in whole cereals and legumes but had considerable reducing effect on phytate levels in the tubers. Further processing of all the intermediate products to ready-to-serve foods achieved reductions in phytate levels. Fermentation and oven-drying are efficient processing methods to remove phytate (85.6%) and polyphenols (52%), respectively, from cassava roots. Sun-drying the leaves, with or without prior steaming or shredding, removes about 60% phytate (Juliien *et al.,* 2008).

Ganiyu (2006) investigated the effects of fermentation on the phytate content of cassava peels and found that there was a significant decrease ($P < 0.05$) in the phytate content of fermented cassava peels (705.1 - 789.7 mg/100g). This decrease was more significant in cassava peels fermented with waste water from naturally fermented cassava pulp (705.13 mg/100g). The unfermented cassava peels had 1043.56 mg/100g phytate content.

Davis *et al.* (2009) concluded that during food processing, phytate can be dephosphorylated which releases the minerals and makes them available for absorption. Fermentation, boiling, and oven-drying cassava roots removed 85.6%, 68.6%, and 31.4% of phytate content, respectively. Fermentation of cassava appeared to be the most efficient processing technique to remove phytate (Davis *et al.*, 2009). Within 48 h, phytate content of cassava roots was reduced from 6.24 to 0.99 mg/g (84% removed), and within 72 h, 85.6% of phytate content was removed (Davis *et al.*, 2009).

The effects of processing cassava roots to gari and eba, and resulted in a loss of 90% phytate, while cooking cassava into tuo, ampesi, or fufu resulted in a loss of 68%.

Recently (FAO, 1990) have shown that cassava, cocoyam and yam contain 624 mg, 855 mg and 637 mg of phytate per 100g respectively. Fermentation reduced the phytate level by 88 percent, 98 percent and 68 percent respectively, reduction being rapid within 48 hours but very slow after 72 hours processing (FAO, 1990). The loss of phytate during fermentation is due to the enzyme phytase, naturally present in the tubers or secreted by fermentative microorganisms. Processing into ‘nbo’ or ‘kokonte’ resulted in a loss of only 18 percent of phytate in cassava and 30 percent each in cocoyam and yam. Oven-drying has only a small reductive effect on the phytate content

compared to fermentation. Cooking also has a significant effect, resulting in decrease of phytate by 62 percent, 65 percent and 68 percent respectively in yam, cocoyam and cassava.

The determination of calcium (Ca), zinc (Zn) and phytate (Phy) contents of 35 Nigerian foods were performed by Adeyeye *et al.(*2000), with levels (mg/100 g) of Ca being 29 – 45 (legumes), 17 – 49 (cereals), 17 –187 (spices) and 38–155 (tuber/roots) while the Zn levels were 0.55 – 2.00 (legumes), 0.67– 1.84 (cereals), 0.3 4– 4.92 (spices) and 1.35 – 7.07 (tubers/roots). Phytate levels were 14 – 344 (legumes), 112–287 (cereals), 35–184 (spices) and 0.0 – 1070 (tubers/roots). It was found that fermentation reduced Phytate levels in *Parkia filicoidea, Sorghum bicolor* and *Manihot esculenta* while Phy level was increased in fermented Zea mays. The Phy:Zn molar ratios calculated for many legumes, cereals, tubers/roots and one spice analysed were greater than 20:1. Corresponding Ca:Phy molar ratios were generally low in legumes (except for *Sphenostylis stenocarpa*, 54:1), cereals and tubers/roots but generally high in spices (except *Irvingia gabonensis*, 2:1). *Dioscorea rotundata, Dioscorea dumentorum* and *Manihot esculenta* have molar ratios of Ca:Phy 1.8, 2.5 and 1.4 respectively while the respective [ca] [Phy]/[Zn] molar ratios were 0.50, 0.54 and 0.62. These results suggest that the bioavailability of zinc in the Nigerian diet may be low due to the high phytate content of the staple foods (Adeyeye *et al.,* 2000).

Although phytate and polyphenols have antioxidant properties, they interfere with digestion and uptake of nutrients (Juliien *et al.,* 2008). Fermentation and oven-drying are efficient processing methods to remove phytate (85.6%) and polyphenols (52%) respectively, from cassava roots. Sun-drying the leaves, with or without prior steaming or shredding, removes about 60% phytate

Emmanuel *et al*. (1990) revealed that phytate level in unprocessed foods were 6.24 ± 0.22 mg of phytate/g of sample (cassava), 8.55 ± 0.45 mg/g (cocoyam), 6.37 ± 0.32 mg/g (yam), 7.34 ± 0.31 mg/g (white maize), 6.86 ± 0.12 mg/g (yellow maize), 8.86 ± 0.20 mg/g (red sorghum),4.49 ± 0.22 mg/g (rice), 8.24 ± 0.22 mg/g (cowpea), and 6.88 ± 0.52 mg/g (soybean). Seventy-two hours of fermentation substantially reduced phytate levels in these foodstuffs, ranging from 80% to 98% for rice, cassava, and cocoyam and from 52% to 65% for sorghum, maize, soybean, cowpea, and yam. Lowering of phytate level was most rapid within the first 48 h of fermentation. Cooking had little reducing effect on phytate level in the whole cereals and legumes but had considerable refducing effect on phytate level in the tubers. Further processing of all the intermediate products to ready-to-serve foods achieved reductions on phytate levels. The pH of the maize dough fell from pH 6.21 to pH 3.10 during fermentation (Emmanuel *et al*.,1990).

Oboh *et al*. (2003) utilised these pure strains of *saprophytes - Aspergillus flavus, Aspergillus niger, Rhizopus oryzae* and *Saccharomyces spp.* (Baker"s yeast and palm wine yeast) to ferment cassava pulp and made into gari and flour.There was a decrease in the phytate content of fungi fermented cassava products [flour (505.6 ± 4.2 – 748.5 ± 2.3 mg/100 g) and gari (373.5 ± 6.2 – 56.7 ± 5.2 mg/100 g)] when compared to the naturally-fermented cassava products [flour (705.1 ± 1.2 mg/100 g) and gari (633.9 ± 3.2 mg/100 g)] and unfermented cassava products [flour (874.4 ± 3.2 mg/100 g) and gari (662.8 ± 6.5 mg/100 g)]. The calculated [Ca][phytate]/[Zn] molar ratios for the products indicated that the fungi fermentation enhanced the bioavailability of zinc from the products. Moreover, values obtained in the present study were far below the critical value of 0.5 mol/kg. This indicates that fungi fermentation would bring about a decrease in the phytate content of cassava products (flour and gari) and consequently improve the bioavailability of zinc from the products.

2.2.3 Effects of processing on tannins level

The results of analysis of leaves of two varieties of cassava - TME1 (local) and TMS30572 (improved) - subjected to African household processing (heat-treated, pounded and cooked and crushed, ground and cooked) by Aduni*et al*. (2008) indicated that this led to the reduction of tannin by 55.2%. These values agreed with the findings of Awoyinka *et al.* (1995). Grinding was found to reduce tannin by 71% (Awoyinka *et al*., 1995).

Oboh and Akindahunsi (2003) indicated that *Saccharomyces cerevisae* fermentation of the cassava into flour and gari did not bring about any significant changes in the tannin. In a different approach, the effect of certain physical and chemical treatment in reducing the levels of tannins in cassava were studied by Padmaja (1989). Drying at 60℃ could reduce the assayable tannin content to a considerable extent. Wilting the whole branches under shade for 16 h followed by drying the destarched leaves at 60 ^{o}C was even more advantageous in reducing the levels of this toxic principle (Padmaja, 1989) . Highly significant reducion in assayable tannin levels could be brought about when the leaves were either sprayed with sodium hydroxide or ammonia which was considered to be the best practical method for reducing the assayable tannin from cassava leaves (Padmaja, 1989).

June (2006) detected low levels of tannins (proanthocyanidins) in dried cassava samples using standard methods of analysis based on extraction procedures. The results of these experiments indicate that tannins present in dried/processed cassava products may be a factor limiting their nutritional value.

In a bid to determine the extent to which condensed tannins (CTs) can affect the use of cassava, as forage, Jess *et al*. (2006) investigated the tannin content of its leaf blade.They revealed that leaf blades generally contain < 20% crude protein (CP). However, neutral-detergent fibre (NDF) obtained from cassava leaf blades contains condensed tannins (CTs) and high levels of CP. The amount of CP in the NDF that is insoluble when treated with pepsin or protease is highly correlated with the amount of CTs in the NDF. CTs in the NDF are rich in prodelphinidin. CTs, may therefore, be an important factor limiting the nutritive value of cassava forage.

2.3 Effects of Processing on the Nutritonal Components of Cassava Products

2.3.1 Effeccts of processing on the protein contents

The analysis of crude protein, amino acid composition, buffer-soluble proteins and free amino acid were carried out on tubers and leaves of cassava by Lila and Chatterjee (2000). Crude protein in tubers were found to vary from 0.98 to 2.28% dry weight and from 21 to 25% in leaves. Free amino acids ranged from 0.120 to 0.345% fresh weight of tubers and buffer-soluble proteins from 2.0 to 2.4 mg/g fresh weight. Conspicuous amounts of arginine was a characteristic feature of protein of all the cassava tubers analysed. Tubers were also rich in lysine, but were limiting in sulphur-containing amino acids, leucine, phenylalanine, and tyrosine. In contrast, leaf protein was found limiting in lysine and histidine, but rich in leucine. In leaves, quantities of all other essential amino acids surpassed that in FAO reference protein. Arginine was less conspicuous in the leaves.

Adeyemi *et al*. (2007) fermented mashed unpeeled whole cassava root meal in airtight plastic packs for 0, 24, 48, 72, and 96 h with nitrogen sources of Caged Layer Waste (CLW), Pig

Excreta (PE) and 1:1 mix of CLW:PE at 0, 25, 50 and 75 g/kg using bovine rumen filtrate as inoculums. The results obtained at the end of the study indicated an improvement in crude protein values of whole cassava root meal when enriched with two common animal wastes and fermented with bovine rumen filtrate. Crude protein (CP) and ether extract (EE) values increased with fermentation duration.

Analysis of leaves of two varieties of cassava - TME1 (local) and TMS30572 (improved) - subjected to African household processing (heat-treated, pounded and cooked and crushed, ground and cooked) and compared for proximate composition, minerals, vitamins and antinutritional factors was carried out by Aduni *et al*. (2008). The results revealed that processing methods had no effect on , protein. However, Awoyinka *et al*. (1995) showed that blanching increased protein content (except Amaranthus) and *in vitro* protein digestibility.

The drying effect of varying light frequencies on the proximate composition of cassava was investigated by Kolawole *et al*. (2009). The results of the proximate composition showed that deep purple had the highest crude protein content (4.21%) compared to others.

Nagib and Costa (1977) screened some wild species collected from various regions of Goias State, Brazil, for protein content in *Manihot* which showed that two of them had a notably high percentage of protein on dry matter basis. The species screened were: *M. oligantha subspecie, Nesteli, M. tripartita Muell, M. zethtneri Ule, and M. anomala pohl*. One variety attracting attention in the screend wild species is *M. oligantha subsp. Nesteli* due to its high protein content combined with a very low level of HCN. The results indicated that protein contents for this species were 7.10 ± 0.58 and the second species has 6.88 ± 1.48. The values for protein of the last two were *M. anomada* (3.74 ± 0.63) and *M. zehatneri* (3.06 ± 0.82).

Guillermo *et al*. (1983) conducted experiments on the nonaseptic, high-temperature production of a fungal biomass from cassava by single-cell protrein (SCP) production . The protein yields were not as high as obtained in the previous small-scale fermentations, with the total crude protein content of the final product having an average of < 35% of dry matter. This was partially due to an incomplete utilisation of carbohydrates.

Etudaiye *et al*. (2009) evaluated fufu flour from 43 Cassava Mosaic Disease (CMD) resistant varieties, in terms of their proximate composition. The results indicaed that moisture content ranged from 5.52 to 12.25%, protein 0.35 to 2.80% and dry matter 87.75 to 94.48%.

Esther *et al*. (2006) used three processing methods (grating, slicing and reconstitution of the starch and fiber, RCF) to obtain the cassava flours from four varieties (Yeshebie, Abasafitta, 175 (V1) and 045 (V2). The result indicated that the protein content of all the four products from the method of slicing was much higher than their corresponding RCF and grated flour samples.

Achinewhu *et al*. (1998) analyzed gari processed from six different cassava cultivars TMS 3575, TMS 3044, hormone treated variety (HTV), TMS 30555, TMS 40944 and TMS 30572. The results showed pH values of: 4.0, 4.0, 3.9, 3.6, 3.4, 3.6 and total titratable acidity of 0.99, 0.99, 0.98, 0.85, 0.96, 0.85 (% lactic acid) for TMS 3575, 3044, HTV, 30555, 30572, and 40944 respectively. Sensory evaluation showed a significant difference ($P < 0:05$) in quality and overall acceptability among the samples while Tukey test showed a difference ($P < 0.05$) between HTV and those of 3575 and 3044. The cassava pulp from the cultivars and their corresponding gari had HCN content (mg/100 g) ranging from 7.9 to 9.3 for pulp and 1.1 to 1.5 for gari, respectively. The 72 hours fermentation period reduced the HCN in all cultivars by 85%, which is considered to be a safe level for human consumption.

Okoro (2007) studied fufu flour obtained from a modified cassava processing method. The flour obtained from the modified process had hydrocyanide (HCN) levels of 200 - 300% lower (10 – 16 mg/kg) than that of the traditionally processed fufu flour (38 mg/kg). Sensory scores showed a general preference for fufu from the modified process in terms of odour, colour, texture, and overall acceptability and absence of repulsive fufu odour.

Cassava leaf samples processed into cassava leaf meal (CLM) and cassava leaf protein concentrate (CLPC) by Ayodeji and Valentine (2005) showed that the protein content of the CLPC was high at 470 g kg^{-1} DM comparable to other conventional protein sources while the crude fibre content was 20 g kg^{-1} DM. The crude fat was high (216 g kg^{-1} DM) and nitrogen free extract low (159g kg^{-1} DM). The amino acid profile of the CLPC showed a favourable balance of both essential and non-essential amino acids especially for lysine, leucine, valine and tryptophan at 6.80, 9.65, 6.30 and 2.31 g/16gN respectively. The nutritive potential, low-cost and the simplicity of the production technology make CLPC attractive as a source of protein in local food production system as a practicable and ameliorative intervention strategy for the endemic protein under-nutrition in most developing regions.

Okolie *et al*. (1992) studied the controlled fermentation of cassava tuber sections using a starter culture consisting of *Citrobacter freundii, Geotrichum spp., Candida spp.* and *Saccharomyces spp.* yielded the most acceptable product 'akpu', with respect to odour and residual cyanide ($P < 0.05$; $P < 0.01$ in some cases). Although traditional fermentation resulted in a significantly higher protein and lower HCN ($P < 0.01$) content than in all controlled fermentations, the product is significantly more odorous and lower in dietary fibre ($P < 0.05$).

Determination of the chemical composition of cassava flour processed by wet fermentation, solid-state fermentation and sun-drying in Tanzanian villages indicated that wet fermentation resulted in lower protein values compared to samples processed by solid-state fermentation and sun-drying. Solid-state fermented samples had higher protein contents than sun-dried samples (Muzanila *et al*., 2000).

Daniel, 1984 investigated the traditionally fermentated and grated cassava used in the production of gari and of retted cassava in many parts of West Africa. The study revealed a decrease in the protein content by about 45%; though, this is contrary to the work of other authors. Traditional fermentation was shown to also cause a decrease in the chemical score of the tuber protein by about 3%.

The effect of traditional processing/preservation methods on the physico-chemical and sensory quality of fermented cassava flour (Kpor umilin) in some areas of Benue State, Nigeria indicated that comparisms made between flour samples prepared in the laboratory from a modification of the traditional process and the traditionally processed flours led to the observation that the traditional sample contained higher moisture (14.15% - 16.81%) than the modified sample (13.85%).

Hydrogen cyanide (HCN) content of the traditionally processed flours was higher (9.90 mg/100 g - 15.00 mg/100 g) than the modified flour (6.40 mg/100 g). The pH of the samples were similar but titratable acidity (TTA) values varied significantly ($P < 0.05$) among the samples (Inyang *et al*., 2006).

Irtwange and Achimba (2009) studied the effect of duration of fermentation on some proximate and sensory parameters in bitter cassava grated and fermented traditionally for a period of five days, to determine the optimum number of days of fermentation for best quality gari. The results of the study as indicated by analysis of variance show that there is high significant effect ($P < 0.01$) of the duration of fermentation of gari on moisture content, ash content, crude fibre, crude fat, crude protein, HCN and swelling index. The regression analysis indicated that whereas moisture content, ash content, crude fibre, crude protein, HCN and swelling index generally seems to increase with increase in duration of fermentation, HCN and crude fat decreased with increase in duration of fermentation. The study recommends that for industry application, cassava mash for gari should be fermented for at least three days. Cassava mash fermented for three days has the HCN reduced to a level tolerable for human consumption; there is an advantage of maximum swelling, in addition to desirable colour, aroma and texture (Irtwange and Achimba, 2009).

Ayankunbi *et al*. (1991) studied the changes in the nutrient composition of three cassava products, 'gari', Lafun and Fufu, as affected by preparation methods. Proximate analysis was carried out on the raw sample and sample of the cooked foods for moisture content, crude protein, energy, sugar, iron, calcium and phosphorus. It was shown that there was a slight and variable decrease in protein content of the products with 'gari' having the lowest amount of protein. The gross energy values of 'gari', 'lafun' and 'fufu' were found to be 381·5 kcal, 357·7 kcal and 180 kcal respectively, compared to 174·0 kcal for the raw sample

Investigations were carried out by Olusola and Ayo (2004) on the changes in the carbohydrate, mineral, and protein contents of cassava during the fermentation production of fufu, indicated

that fermentation caused a reduction in the starch content, the total soluble and reducing sugar levels increased during the first 36 and 24 h, respectively, then fell in concentration for the remainder of the 96 h fermentation. The fermentation process caused an increase in the concentration of calcium (+12%) in cassava but reductions in the levels of magnesium (−53%), potassium (−71%), sodium (−68%), manganese (−60%), iron (−50%), copper (−7%), zinc (−85%), and phosphorus (−67%). Despite these losses, the fermented product fufu, was found to contain appreciable quantities of calcium, magnesium, and potassium. The fermentation caused an overall 20% reduction in the protein content. The protein content which decreased during the first 72 h, showed a rapid increase during the last 24 h of the fermentation

2.3.2 Effects of processing on the fat content

In an attempt to enhance the nutritional quality of cassava products (flour and gari), Oboh and Akindahunsi (2003) used *Saccharomyces cerevisae* in the fermentation (solid media) of cassava pulp. The mash obtained was subsequently processed into flour and 'gari'. The analyses revealed that there were significant increase in the fat [flour (4.5%), gari (3.0%)] contents.

2.3.3 Effects of processing on the other nutritional consttuents

It has been shown that prolongation of fermentation period reduced the dry matter, crude fiber, ash, Ca, P and HCN values (Adeyemi *et al.*, 2007).

Analyses of the leaves of two varieties of cassava - TME1 (local) and TMS30572 (improved) - subjected to African household processing (heat-treated, pounded and cooked and crushed, ground and cooked) and compared for proximate composition, minerals, vitamins and anti-nutritional factors that processing methods had no effect on ash, lipids, fiber, total carbohydrate,

carotene, calcium, magnesium, potassium, sodium, phosphorus, copper, zinc and manganese but recorded loss in free sugars (23.2% reduction), ascorbic acid (77.7% reduction), thiamine (37.1% reduction). However, Awoyinka *et al.* (1995) showed that blanching decreased ash, minerals, and dietary fibre. On the contrary, iron level increased from three fold to five fold with grinding, but not with the pounding process (Aduni *et al*., 2008).

Mash prepared from cassava peels was inoculated with either *Sacchromyces cerevisiae* or *Candida tropicalis* and then left to ferment for 7 days. Chemical analysis of the fermented mash showed substantial decrease in carbohydrate content of the mash. There was also slight increase in the ash, fibre and lipid contents of the fermented mash (Antai and Mbongo, 2005).

Changes in the sugar and cellulose of three agro-industrial by-products (cassava peels, brewers dried grains and maize offal) after fermentation with *Aspergillus niger, Aspergillus flavus* and *Penicillium sp.* in solid state were determined by Eustace (2004). Cellulose was significantly reduced ($P < 0.05$) in all the agro wastes by all the fungi after 14 days. Highest percentage reduction was achieved by *A. niger* in all the agro wastes; 36.51% for cassava peels (CP), 35.87% for brewers dried grain (BDG) and 35.80% for maize offal (MO). There was a corresponding build up of all the soluble sugars in the substrate up to 14 days. Beyond day 14, the sugar level indicated began to fall and then showed no more significant degradation of the cellulose.

Fermentation was carried out using Pure strain of *Aspergillus niger* on gari and cassava flour.These were then subjected to proximate and mineral compositions by Oboh *et al*.(2004). There was no significant increase ($P > 0.05$) in the ash and crude fibre contents (Oboh *et*

al.,2002). The mineral composition (Na, K, Ca, Zn, Fe and Mg) of the products was considerably low, though gari had higher Na, K, Ca and Zn than the flour.

In an attempt to enhance the nutritional quality of cassava products (flour and gari), Oboh and Akindahunsi, (2003) used *Saccharomyces cerevisae* in the fermentation (solid media) of cassava pulp. The mash obtained was subsequently processed into flour and gari. On analyses there were significant decrease in carbohydrate [flour (77.9%), gari (84.5%)] and mineral (Zn, Mg, Fe, Ca, Na and K) contents of the cassava products, except in the fermented gari where there was significant increase in the Mg and Fe contents. However, *Saccharomyces cerevisae* fermentation of the cassava did not bring about any significant changes in the crude fibre or ash contents of the cassava products. Heavy metals, such as Cu, Ni and Pb, were not detected in either the fermented or unfermented cassava products. Increase nutrient was more pronounced in cassava flour while the decrease in anti-nutrient was morr pronounced in gari.

Three processing methods (grating, slicing and reconstitution of the starch and fiber) were used by Esther *et al.* (2006) to obtain cassava flours from four varieties (Yeshebie, Abasafitta, 175, (V1) and 045 (V2). Reconstitution of the starch and fiber had the highest starch content.

Adewusi *et al*. (2004) estimated changes in pH, titratable acidity and mineral content (Ca, Fe, Mg, Zn) in processed cassava products and determined the mineral content of raw and blanched *Amaranthus* vegetable. pH of fresh cassava (6.5) decreased as total organic acid (0.07%) increased with fermentation period. Fufu and lafun had the lowest pH and the highest total organic acid contents. Fermentation of cassava increased the total Ca and Fe contents, reduced Mg level while Zn remained fairly constant in grated cassava but was reduced when soaked in water (for the preparation of fufu and lafun). Fermentation also increased the availability of these

selected minerals in both cassava products and simulated cassava-vegetable diets. Blanching reduced the mineral content of amaranthus vegetable but increased mineral availability.

The effect of different cooking times and steeping times on the colour and flavour of cassava slices were evaluated by Christian (2009). Evaluation of the slices were carried out under cooking times of 20 min, 30 mins, 40 min, 50 min and 60 min while the steeping times were 12 h, 15 hs, 18 h, 21 h and 24 h. The study showed that increasing cooking and steeping times adversely affected the colour quality. The soaking of the cassava slices in water (which is technically termed steeping) resulted in the development of slimy material on the slices.

Aryee (2006) prepared flours from 31 cassava varieties and evaluated their physico-chemical properties and pasting characteristics. The results showed that starch content ranged from 67.92% for sample 91/0055 to 88.11% for sample I93/0665. Amylose content of cassava flour varied from 10.9% (94/0050) to 44.3% (I93/0548). The cassava flour had low swelling power values ranging from 5.87 (Abasafitaa) to 13.48(I89/02184).

The chemical composition of cassava flour processed by wet fermentation, solid-state fermentation and sun-drying in Tanzanian villages, were determined by Muzanila *et al.* (2000). The study reported that wet fermentation led to lower levels of vitamin C, reducing sugars and also low pH values compared to samples processed by solid-state fermentation and sun-drying. Solid-state fermented samples had higher reducing sugars than sun-dried samples. No mycotoxins (aflatoxins) were detected in the cassava samples.

The traditional fermentation of grated cassava used in the production of gari and of retted cassava in many parts of West Africa resulted in low mineral and an approximately 69%

decrease in the phosphorus content, a 65% decrease in magnesium, a 76% decrease in potassium and a 50% decrease in the sodium content. Fermentation also causes substantial reduction in the absolute quantity of the amino acids. Traditional fermentation causes a decrease in the chemical score of the tuber protein by about 3% and also accounted for an approximately 2% in the biological value of the tuber meal (Daniel, 1984).There was an approximately 3.8% loss of dry matter in the fermented meal.

2.4 The Chemistry of Some Components in Cassava Products

2.4.1 Chemistry of phytic acid

Phytic acid (IP6) is a highly reactive acidic compound that readily binds mineral cations to form complexes called phytins. The chemical characteristics of IP6 has been found to influence exogenous (diet) and intestinal phytase efficacy and the availability of both phytin-P (PP) and any mineral bound to IP6 (Angel *et al*., 2002).

Phytin is the most commonly thought of as an antinutrient, because of its ability to complex or bind mineral cations in the seed or diet, rendering these bound cations as well as the PP partially or completely unavailable to the animal (Angel *et al.,* 2002). The complexing of phytic acid with nutritionally essential elements and the possibility of interference with proteolytic digestion have been suggested as responsible for anti-nutritional activity (Oboh and Elusiyan, 2007).

Myo-inositol-1,2,3,4,5,6-hexakis dihydrogen phosphate (IP6), an organic phosphate, is a phosphorylated cyclic sugar alcohol. Phytic acid (a powerful chelator) is known to have 12 replaceable protons or reactive sites. Six are strongly acidic, with pK of 1.5 to 2.0; two are weakly acidic with a pK of approximately 6.0, and four are very weakly acidic with pK of 9.0 to

11.0. This means that at pH normally encountered in feeds and in the digestive tract, phytin will carry a strong negative charge and is capable of binding di- and tri-valent cations such as Zn^{2+}, Cu^{2+}, Ni^{2+}, Co^{2+}, Mn^{2+}, Fe^{2+} and Ca^{2+} in very stable complexes (Spinelli, 1980), thus reducing the availability of these complexed minerals as well as that of the PP to the animal (Angel *et al*., 2002). The order of potency of selected minerals to inhibit PP hydrolysis by phytase at pH 7 is Zn^{2+}>>Fe^{2+}> Mn^{2+}> Fe^{3+}> Ca^{2+}> Mg^{2+} (Angel *et al*., 2002; Deolankar, 2001).

According to Deolankar (2001), phytates chelate several minerals in the lumen of intestine and reduce the availability of iron to pathogenic flora (free iron is required by pathogenic flora of the gut).The ability of the different metal ions to inhibit PP hydrolysis was related to the stability of the complex, the pH of the solution, and the phytate to mineral molar ratio.

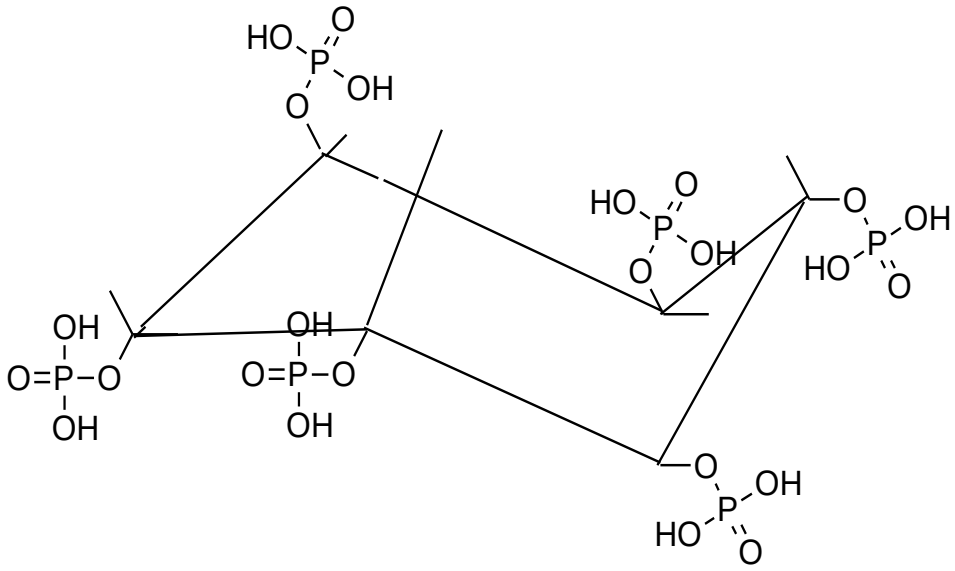


Figure 2.2: Structure of phytic acid as proposed by Posternak

(www.publichealth.pitt.edu/supercourse/SupercoursePPT/25011-26001/25371.ppt)

2.4.2 Phytic acid chelation

As a powerful chelator, phytic acid bonds with free metal ions from solutions. Phytic acid (IP6) present in mature seeds effectively inhibit Ca and Zn uptake. Calcium deficiencies have been reportedly realised in growing children and the old aged.Vitamin D is degraded very fast in individuals having calcium deficiency.This could be the reason why vitamin D deficiency has been common in sunny countries like India.

Magnesium is also required for proper metabolism of Vitamin D. Avitaminosis D is a component cause of several diseases (Spinelli, 1980).

In addition to complexing with macro- and micro-minerals, intrinsic in seeds and those added to diets, IP6 is known to form complexes with proteins and starches. Proteins are found to be able to bind directly with IP6 through electrostatic charges at low pH or through salt bridges formed at high pH,. Starch binding occurs as a result of hydrogen bond formation. The binding of IP6 with protein and starch may also reduce the availability of these nutrients from the diet (Angel *et al.*, 2002).

Furthermore, the complexing of IP6 with proteins or starches influences the degree of ionization of the complex and the ability of phytin to complex with minerals, potentially changing the efficacy of different phytases.

In essence, the strong chelating properties of phytic acid (IP6) present in plant-based diets were shown to result in a large reduction in the efficacy of phytase when the IP6-mineral complexes are present, regardless of the source of phytase, varying sizes of soluble IP6-mineral complexes

with larger complexes reducing phytase efficacy and calcium, rather than other mineral ions in the diet (Angel *et al.*, 2002).

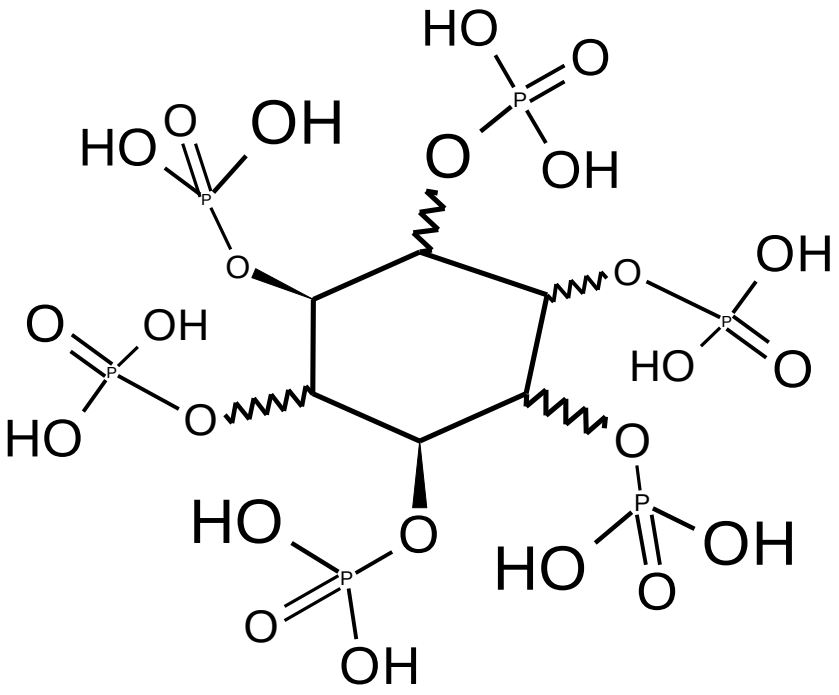


Figure 2.4: Structure of phytic acid as proposed by Anderson

Phytate is not digestable to humans or non-ruminant animals, so it is not a source of either inositol or phosphate if eaten directly. Morever, it chelates important minor minerals such as Zn and Fe, and to a lesser extent, also macro minerals such as calcium and magnesium (Angel *et al.*, 2002).

2.4.3 Significance of phytic acid in agriculture

Phosphorus in phytate form is, in general, not bioavailable to non-ruminant animals because they lack the digestive enzyme phytase, which is required to separate phosphorus from the phytate

molecule. On the other hand, ruminants readily use phytate because of the phytase produced by rumen microorganisms.

The bioavailability of phytate phosphorus can be increased by supplementation of the diet with the enzyme phytase. Also, viable low-phytic acid mutant lines have been developed in several crop species in which the seeds have drastically reduced levels of phytic acid and concomitant increases in inorganic phosphorus (Angel *et al.*, 2002).

2.4.4 Significance of phytic acid in food science

Phytic acid is found within the hulls of nuts, seeds, and grains. In-home food preparation techniques can reduce the phytic acid in all of these foods. Simply cooking the food will reduce the phytic acid to some degree. More effective methods are soaking in an acidic medium during lactic acid fermentation.

Phytic acid (IP6) has a strong binding affinity to important minerals such as calcium, magnesium, iron, and zinc. When a mineral binds to phytic acid, it becomes insoluble, precipitates and so nonabsorbable in the intestines. This process can therefore contribute to mineral deficiencies in people whose diets rely on these foods for their mineral intake, such as those in developing countries. Contrary to that, one study correlated decreased osteoporosis risk with phytic acid consumption. It also acts as an acid, chelating the vitamin niacin, the deficiency of which is known as pellagra. In this regard, it is an anti-nutrient, despite its possible therapeutic effects. For people with a particularly low intake of essential minerals, especially those in developing countries, this effect can be undesirable (Oboh and Elusiyan, 2007).

Phytic acid may be considered a phytonutrient, providing an antioxidant effect. Phytic acid mineral binding properties may also prevent colon cancer by reducing oxidative stress in the lumen of the intestinal tract. It is now believed that phytic acid found in the fibre of legumes and grains is the major ingredient responsible for preventing colon cancer and other cancers.

It has been shown that phytic acid (IP6) is protective against Parkinson's disease *in vitro*. The compound significantly decreased apoptotic cell death induced by 1-methyl-4-phenylpyridinium in a cell culture model. It is also known that, at least in rodents, phytic acid crosses the blood-brain barrier, and so, there is a strong possibility that neuroprotection occurs *in vivo* as well.

IP6 chelating effect may serve to prevent, inhibit or even cure some cancers by depriving those cells of the minerals (especially iron) they need to reproduce. The deprivation of essential minerals like iron would, much like other broad treatments for cancers, also have negative effects on non-cancerous cells.

IP6 also found application in radiotherapy where it is one of few chelating therapies for uranium removal (Spinelli, 1980).

Ironically it has also been shown that IP6 is a required cofactor for YopJ, a toxin from Yersinia pestis. It is also a required cofactor for the related toxin AvrA from *Salmonella typhimurium* (Angel *et al.*, 2002).

Table 2.1: Sources of Phytic Acid from food (Spinelli, 1980)

Food	[% minimum dry]	[% maximum dry]
Sesame seeds flour	5.36	5.36
Brazilnuts	1.97	6.34
Almonds	1.35	3.22
Tofu	1.46	2.90
Linseed	2.15	2.78
Oat Meal	0.89	2.40
Beans, pinto	2.38	2.38
Soy protein concentrate	1.24	2.17
Soybeans	1.00	2.22
Corn	0.75	2.22
Peanuts	1.05	1.76
Wheat flour	0.25	1.37
Wheat	0.39	1.35
Soy beverage	1.24	1.24
Oat	0.42	1.16
Wheat germ	0.08	1.14
Whole wheat bread	0.43	1.05
Brown rice	0.84	0.99
Polished rice	0.14	0.60
Chickpeas	0.56	0.56
Lentils	0.44	0.50

2.4.4 Chemistry of tannins

Salminen *et al*. (2011) described plant tannins as distinctive group of polyphenolic polymers of relatively high molecular weight (M.W = 1000 to 20,000). Tannins are categorised as hydrolysable tannins (HTs) or condensed tannins (CTs or Proanthocyandins) on the basis of their structure and reactivity.

HTs were shown to be of low M.W (500-3000) and are polyesters of Gallic acid (gallo tannins) and hexahydroxy-diphenic acid (ellagitannins) with a central polyols such as sugars/glucose and phenolic such as catechin.

CTs, M.W. (1900-28000) have no carbohydrate core and comprises of a group of polyhydroxy-flavan-3-ol oligomers and polymers linked by carbon-carbon bonds between flavanol subunits (Salminen *et al*., 2011)

Tannins are astringent, bitter tasting compound, being chemically referred to as a broad class of polyphenols. They are often differentiated from other polyphenols by the fact that, tannins precipitate proteins.

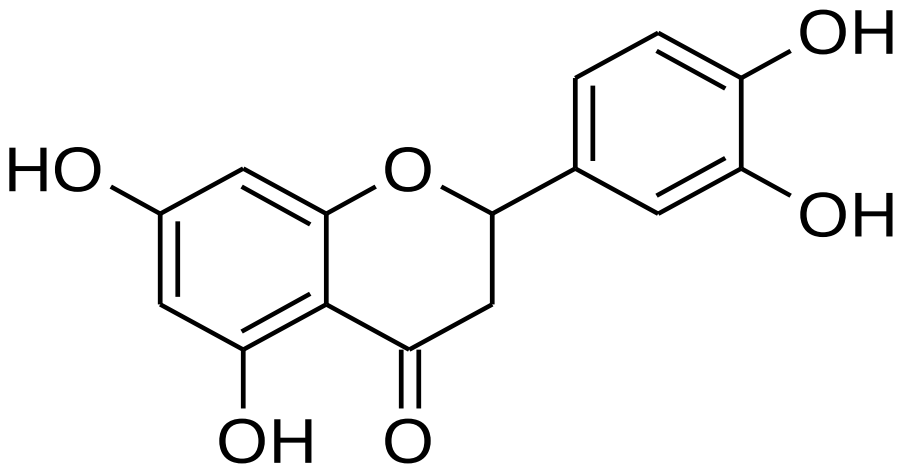
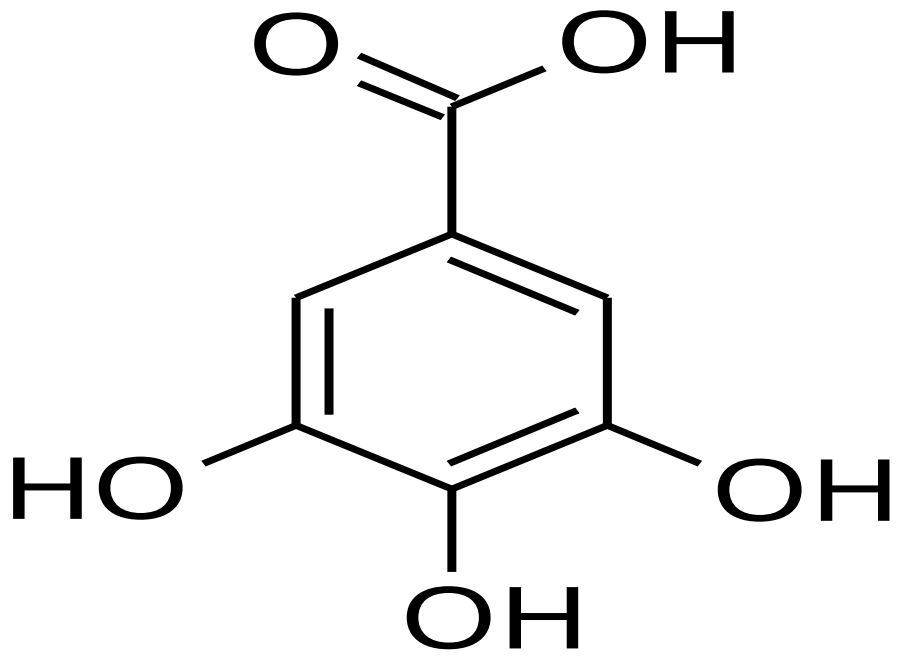


Figure 2.5: Structure of catechin [catechin, a common (and fairly simple) tannin found in a brew kettle]



F igure 2.6: Structure of gallic acid (hydrlysed tannin)

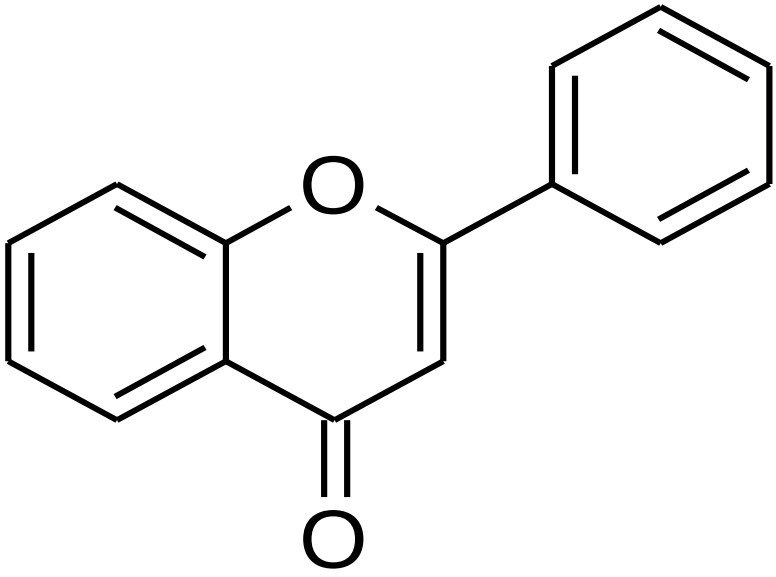


Figure 2.7: Structure of flavone (a condensed tannin)

Hydrolyzed tannins have been found to have a very low bioavailability following oral ingestion, due to their poor lipid solubility and ability to form strong complexes with proteins. Hydrolysis of tannins occurs mostly in the large bowel at neutral to alkaline pHs (Catherine, 2009; Oboh and Elusiyan, 2007).

Hydrolysed tannins were indicated by Catherine (2009) to inhibit the absorption of iron, which may, if prolonged, lead to aneamia. Tannins are known to be metal ion chelators, which render the ion unavailable to the body. Tannins only reduce the bioavailability of plant sources of iron, while animal sources of iron are left available for absorption (Catherine, 2009). Condensed tannins do not interfere with iron absorption. They are preferable for human consumption and therapeutic treatment (Catherine, 2009).

Tannins have been shown to have the ability to interact with and precipitate proteins including the proteins found in animal skin. They are said to be potential metal ion chelators, protein

precipitating agent and biological antioxidants (Ann, 2002; Catherine, 2009). Phenolics can affect the biological availability or activity of metal ions by chelating the metals. Chelation requires appropriate patterns of substitution in the pH above the pKa of the phenolic group; tannin-chelated ions are thus not bioavailable. So, consumption of large quantities of tannin-rich food is sometimes associated with deficiency diseases such as aneamia. In many ecosystems, the slow decomposition of tannin-rich leaves has been attributed in part to the low levels of biologically available metal ions (Ann, 2002). The populations of microfauna essential to leaf decomposition and soil fermentation are unable to grow when metals are unavailable. Metal ion chelation can also alter the redox potential of the metal, or prevents its precipitation in redox reactions. Thus, metal ion chelators can be inhibitors or enhancers of tannin-driven oxidative reactions, making high level of dietary tannin to interfere with protein utilisation (Ann, 2002).

Although, dietary tannins are often percieved as detrimental because of their potential effect on protein digestibility or metal ion availability. It is also possible that tannins are beneficial (Silanikove *et al*., 2001).

Antioxidants are widely believed to be an important line defense against oxidative damage, which has been implicated in ranges of diseases, including cancer, cardiovascular disease, arthritis and ageing. Biological antioxidants are generally divided into three groups: enzymes, such as superoxide dismutase, inhibitors of radical formation and free radical quenching agents. (Ann, 2002; Silanikove *et al*, 2001).

Table 2.2 Concentration of Proanthocyadins (PAs) in common foods

Food	Total PAs	Type
Grape seed (dry)	3532 ± 105.8	PC
Apple, red delicious with peel	125.8 ± 6.8	PC
Pecans	494.1± 86.2	PC, PD
Red wine	313 ± 5	PC, PD
Cranberryjuice cocktail	231 ± 2	A, PC
Grape juice	524 ± 2	PC, PD
Cinnamon, ground	8108.2 ± 424.2	A, PP, PC

(PP, PC and PD are propelargonidins, procyanidins, and prodelphinidins respectively. 'A' indicates the existence of A-type Pas) (Catherine, 2009)

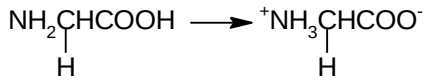
Tannins impart dull colour on cassava products, and this has effects on the market value of the products (Oboh and Elusiyan, 2007).

2.4. 5 Chemistry of proteins

The word protein comes from the Greek word proteios, meaning "of first rank." Proteins can function as a building material, in teeth and bones and muscles, and can serve as enzymes, hormones and neurotransmitters (Antonio, 2014).

Protein consists of macromolecules called polypeptides, made from monomers called amino acids. Most proteins also include traces of other organic molecules or metal ions, which give it its characteristic biological function.

Amino acids are **(**the monomer units for polypeptides) are a group of about 20 -amino acids, all of which share the following strucutral features.

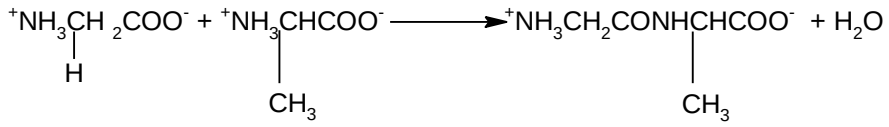


Glycine Dipolar ionic form of glycine

Amino acids are usually found in their dipolar ionic form because of internal self-neutralization. A proton (hydrogen nucleus) is transfered from the proton-donating carboxyl group to the proton accepting amino group (Oracle ThikQuest Education Foundation, 1996).

The G stands for a side chain. There are about 20 side chains which give the 20 different amino acids. The simplest one is just a H, which makes glycine (Gly).

The carboxyl group of one amino acid becomes joined to the amino group of another by a peptide bond (amide bond). For example, this is the linking of glycine and alanine:



glycine (Gyl) + alanine (Ala) ==> glycylalanine (Gly-Ala) + water

Glycylalanine is a dipeptide because it has two amino acids linked by a peptide bond (CO - NH). Also, because the molecules produced are still dipolar ions, more amino acids can be put together. Proteins have hundreds, thousands or sometimes even millions of these amino acids (Oracle ThikQuest Education Foundation 1996; Antonio, 2014).

2.5 Diseases Related to Cassava Toxicity

2.5.1 Stunting of children

Children in the Democratic Republic of Congo who ingested large amounts of cyanide from cassava were found to be stunted. This may be due to the fact that ingested cyanide is converted into thiocyanate by a reaction that uses up sulphur-containing amino acids which are essential in the diet, because they can only be obtained from the food consumed (Dulce *et al*., 2008).

A shortfall of these amino acids would limit protein synthesis that could cause stunting (Dulce *et al*., 2008). The diseases related to cassava toxicity include the acute cyanide intoxication, endemic goiter and neurological disorders (nutritional neuropathies) such astropical ataxic neuropathy and Tropical ataxic neuropatyh (FAO, 1990). Report also had it that large chunk of

Ubangi population in Zaire suffered from endemic goitre. Neurological disorders have been reported in Nigeria, Tanzania and Zaire (FAO, 1990). Its causative role has been confirmed in the pathological condition of acute cyanide intoxication and in goitre. There is also some evidence linking two types of paralysis to the combined effects of a high cyanide and low sulphur intake, that could result from a diet dominated by inefficiently processed cassava. In these two diseases, tropical atoxic neuropathy and epidemic spastic paraparesis, paralysis follows causing damage to the spinal cord.

Cassava toxicity may be acute and/or chronic. Acute toxicity results from ingestion of a lethal dose and death is caused by the inhibition of cytochrome oxidase of the respiratory chain by cyanide (FAO, 1990). Chronic cyanide toxicity on animals can affect both the growth and reproductive phases of development. Consumption of cassava and other foodstuffs high in cyanide can cause acute cyanide poisoning and death in man and other animals (FAO,1990). Since lethal dose of cyanide is proportional to body weight, children tend to be more susceptible to outright poisoning than adults (Dulce *et al*., 2008).

Symptoms of cassava toxicity appear four to five hours after ingestion of raw or insufficiently processed cassava and consist of vertigo, vomiting dizziness, headache, nausea, stomach pains, diarrhoea, collapse and in some cases death within one or two hours (Dulce *et al*., 2008; FAO, 1990). Treatment of these symptoms is quite effective and cheap. The principle is to increase the detoxicating capacity of the patient by giving an intravenous injection of thiosulphate and thereby making more sulphur available for conversion of cyanide to thiocyanate.

CN^- → SCN^-

cyanide ion thiocyanate ion

Bede (1980) classified the toxicity of cassava cultivars as follows: Innocuous: less than 50 ppm fresh peeled tuber; Moderately poisonous: 50–100 ppm fresh peeled tuber; Dangerously poisonous: more than 100 ppm fresh peeled tuber.

Cyanide taken in cassava-based diet is detoxified in the body, resulting in the production of thiocyanate. Thiocyanate has the same molecular size as iodine and interferes with iodine uptake by the thyroid gland. Under the conditions of high ingestion of inefficiently processed cassava, there may be a chronic cyanide overload leading to a high level of serum thiocyanate of 1 to 3 mg/100 cm^3, compared to a normal level of about 0.2 mg/100 ml. Under such conditions there is an increased excretion of iodine and a reduced iodine uptake by the thyroid gland, resulting in a low thiocyanate/iodine (SCN/I) excretion ratio. The value of the threshold level for this ratio seems to be three after which endemic goiter (enlargement of the thyroid gland) and cretinism (shortness of stature and severe mental impairment) appear. This phenomenon can occur only when the iodine intake is below about 100 mg per day. At SCN/I ratios of lower than two there is a risk of endemic cretinism, a condition characterized by severe mental retardation and severe neurologic abnormalities (Delange *et al*., 1989; Kumar, 1992).

In these regions where there is iodine deficiency, which causes goitre and cretinism, cyanide intake from cassava exacerbates these conditions (Dulce *et al*., 2008; Paula *et al*., 2005). Therefore the goitrogenic action of cassava depends on the glucoside levels in fresh roots, the effectiveness of processing, the frequency of cassava consumption and the iodine intake (Delange *et al*., 1989). The effect of thiocyanate mimics entirely the ones of iodine deficiency.

Studies in Zaire have shown that the population of Ubangi, who consume a high amount of sun-dried but unfermented cassava products, have a low SCN/I ratio of 2 to 4 and suffer from

endemic goitre and cretinism. Whereas in Kim, where fermented and dried cassava paste is eaten, the SCN/I ratio goes up to three to five and there is a low incidence of goitre. In Bas Zaire, where properly processed cassava products are eaten, the SCN/I ratio is higher than seven and there is no goitre. A low ratio leads to abnormal levels of the thyroid stimulating hormone (TSH) and low thyroxine (T4). In pregnant women, the thiocyanate level of the cord blood was proportional to the maternal serum thiocyanate level, indicating that thiocyanate can cross the placental barrier and affect the foetus. However, there is very little thiocyanate in breast milk indicating that the mammary gland does not concentrate thiocyanate and so breast-fed infants are not affected (Delange *et al.*, 1989).

When iodine supplements are given, for example, by adding potassium iodide to local supplies of salt, goitre is reduced in spite of a continued high intake of cassava products. Where salt intake is small or variable, iodised oil, given by mouth, provides protection for one to two years.

2.5.2 Tropical ataxic neuropathy (TAN)

TAN disease is common in a particular area in Nigeria where a lot of cassava is consumed without the addition of sufficient protein-rich supplementary foods to provide an adequate supply of sulphur amino-acids for the detoxification of ingested cyanide (Bede, 1980). The consumed cassava product, called purupuru, is processed by an insufficient fermentation of the cassava, which leaves a residual cyanide content of up to 0.10 μg/g. As much as two kg of this foodstuff is consumed daily, leading to the ingestion of about 50 mg of cyanide. The toxic level for an adult is about 60 mg. The clinical picture is dominated by damage to one of the sensory tracts in the spinal cord, resulting in an uncoordinated gait called ataxia. In West Africa (particularly Nigeria), Tanzania, Uganda, Kenya, the West Indies and tropical Asia, there is a disease called

tropical ataxic neuropathy (TAN), which generally occurs in older people who have consumed a monotonous cassava diet over years. TAN is progressive and causes unsteady walking, produces loss of sensation in hands, loss of vision, deafness and weakness. Until recently long-term cyanogen intake was linked with the occurrence of TAN, but recent work has shown that the situation may be more complex (Dulce *et al.*, 2008).

When patients are brought to the hospital they have a high plasma thiocyanate level, they are put on a hospital diet on admission, which is highly nutritious and includes cassava only twice a week. Within a short period, the plasma thiocyanate level returns to normal, and the patients recover. However, on discharge, they go back to their original diet of cassava and so the condition reappears.

All the cases reported came from the area where cassava is cultivated and eaten in large quantities, with no cases in the nearby areas where yam predominates. A change in the diet of the population at risk in Nigeria, has reduced the incidence of this disease.

2.5.3 Epidemic spastic paraparesis

This is a situation of depending on very toxic varieties of cassava as a food security crop (Cliff *et al.*, 1984). In parts of Mozambique, a bitter toxic type of cassava is often planted as a food reserve because of its high yield. As cassava constitutes about 80 percent of the basic diet, there is nominally a standard method of preparation which makes the cassava safe for consumption. Cassava, containing about 327 mg HCN/ kg, is peeled, sliced and sun dried for about three weeks after which the cyanide level is reduced to about 95 mg/kg. It is then pounded to a flour

and mixed with hot water to make a paste called chima. This paste is normally eaten with a relish of beans, fish or vegetables, to provide a well balanced meal (FAO, 1990.)

2.5.4 Konzo

In Eastern, Southern and Central Africa, there is a disease called 'konzo' a local name which means 'tied legs', which causes irreversible paralysis of the legs, particularly in children and in women of child-bearing age. It is an upper motor neurone disease of sudden onset. Konzo is persistent in some districts of Nampula Province of Mozambique and larger outbreaks and epidemics occur as a result of droughts and war. The linamarin content of cassava flour is more than double during drought, which leads to outbreak of konzo; most recently there were more than 100 cases in Nampula and Zambezia Provinces due to drought in 2005 (Dulce *et al*., 2008).

The recent five-year civil war in the Democratic Republic of Congo (DRC) caused millions of deaths and forced people to live off the land and eat bitter cassava roots from the bush without processing, which caused many thousands of konzo cases in DRC. There have been more than 2000 cases of konzo in Mozambique since 1980 and a similar number of cases in Tanzania. Konzo occurs in Cameroon and the Central African Republic and may also be present in other eastern, southern and central African countries (Dulce *et al*., 2008; Paula *et al.*, 2005).

When cassava is eaten, most of the ingested cyanide is converted into thiocyanate, a reaction catalysed by the enzyme rhodanese, which uses up part of the pool of S-containing essential amino acids, methionine and cysteine/cystine. These amino acids are essential in the diet because they can only be obtained from the food consumed. A shortfall of these S-containing amino acids

would limit protein synthesis and could cause stunting growth in children, as was in a study in DRC (Dulce *et al*., 2008).

The reliance on cassava as a food source and the resulting exposure to the goitrogenic effects of thiocyanate has been responsible for the endemic goiters in Akoko area of South Western Nigeria. Historically, people economically forced to depend on cassava, risk chronic poisoning diseases, such as tropical ataxic neuropathy (TAN), or such malnutrition diseases as kwashiorkor and endemic goitre (Spinelli, 1980).

2.6 Compositional Studies of Cassava Tubers and Leaves

The phytochemical, nutritive and anti-nutritive composition of cassava tubers and leaves were investigated by Oat *et al*. (2005). The presence of alkaloids, flavonoids, tannins, cardiac glycosides, anthraquinone, phlobatinnins, saponins and anthrocyanosides in aqueous and ethanolic extracts of raw tubers and leaves of cassava were determined. The proximate, moisture, fat, fibre, protein, ash and carbohydrate contents in the raw and boiled cassava tubers and leaves were determined. Vitamins A, C and E, antinutrients such as tannins, oxalate, phytate, trypsin inhibitor activity and some minerals were also evaluated by the researcher.

The aqueous and ethanolic extracts of the raw cassava tubers have alkaloids, flavonoids, tannins, reducing sugars and anthocyanosides, but do not contain cardiac glycosides, anthraquinone, phlobatinnins and saponins. The raw cassava leaves contained more alkaloids, flavonoids, tannins, anthraquinone, phlobatinnins, saponins, reducing sugars and anthrocyanosides, but do not contain cardiac glycosides. The proximate composition of the raw and boiled cassava tubers were not significantly different ($P > 0.01$), except in the carbohydrate, fat and moisture. Raw

cassava leaves contain more crude fibre and protein as compared to the raw or boiled cassava tubers. Vitamins A, C and E and minerals (calcium, magnesium, phosphorus, iron, sodium and chloride ions) were identified in the raw and boiled cassava tubers and raw leaves, their levels were significantly reduced by boiling (Oat *et al*., 2005). Raw cassava leaves contain more antinutrients, such as tannins, oxalate, phytate and higher trypsin inhibitor activity than in the raw tuber.

Analysis of cyanogenic potential, linamarin, acetone cyanohydrin and free HCN/CN^- of 179 cultivars of cassava root grown in Oxisol Soil at Muara Experimentation, West Java, Indonesia was conducted by Hidayat *et al.* (2000), using picrate paper kits, reportedly introduced by Bradbury *et al.* (1999). Although the average content of cyanogenic potential of the 179 cassava cultivars was 82 ppm It was indicated that only 6.8% of the cyanogenic potentials was in the form of HCN/CN^- (5.6 ppm), 23% as acetone cyanohydrin (19.9 ppm), and most of the remainder (70%) as linamarin (57.1 ppm). The cyanogenic potential content clustered into very high levels (234 – 138 ppm) found in 10% of 179 cultivars, high (134 – 84 ppm) in 15% cultivars, medium (81 – 55 ppm) in 17% cultivars, low (54 – 36 ppm) in 19% cultivars, and very low (35–9 ppm) in 40% cultivars. The linamarin, acetone cyanohydrin and HCN/CN^- were also clustered into 5 levels (Hidayat *et al*., 2000).

Analyses of whole cassava plant by Adegbola and Asaolu (1980), indicated that cassava peel represents about 8-10% of the root dry matter. The peel is high in soluble carbohydrates (62%) and low in fibre (16%) with a moderate level of nitrogen (1%). However, previous analyses from other work showed lower nitrogen levels, higher fibre and higher soluble carbohydrate from the sweeter variety compared to the ones used by Adegbola and Asaolu (1980). Recent work with

the new bitter varieties indicated that fresh cassava peel has a pH of 5.7, and drying substantially increased the percent dry matter content, as well as the ash content, with little effect on the crude protein (Adegbola and Asaolu, 1980).

Oliver (2006) determined the cyanide level in cassava plant. The sample averages obtained were 23.5 ppm for the roots, 15.5 ppm for the leaves, 8.0 ppm for the sap and 7.0 ppm for the flour. One must eat at least 1.28 kg of roots, 1.94 kg of leaves, 3.75 kg of sap, and 4.29 kg of flour to reach the danger level for being prone to intoxication of cyanide. These values were below the suggested danger level of 30 ppm.

In the first experiment conducted by Phanthavong and Metha (2004), a local and an introduced cassava variety (Rayong72; RY72) from Thailand were studied to determine the effects on chemical composition during three harvests (3, 5 and 7 months after planting). The dry matter (DM) and protein yields of the cassava variety RY72 at each harvest were higher than the local variety. Condensed tannin was 3.3 to 3.4 and 3.5 to 3.8 % in RY72 and in the local variety respectively (Phanthavong and Metha, 2004).

Albert *et al.* (2005) studied five cassava genotypes: Rayong 5, Kaesetsart 50 (KU50), Rayong 2, Hanatee and KMUL 36-YOO2 (YOO2), and showed that the cassava contained 9.2 - 12.3% moisture, 1.2 - 1.8% crude protein, 0.1 - 0.8% crude lipid, 1.5 - 3.5% crude fibre, 1.3 - 2.8% ash, 80.1- 86.3% carbohydrate, 1406 - 1465 kJ 100 g^{-1} DM and 95 - 135 mg g^{-1} of phytic acid. Mineral contents were 10.9 - 39.9, 15.2 - 32.3 and 9.3 - 54.1 mg g^{-1} for Ca, Mg and P respectively. The ranges 221 - 328, 4.7 - 25.8, 1.41 - 4.25, 0.29-1.73 and 1.2 - 4.44 mg g^{-1} were for K, Na, Zn, Mn, Cu and Fe respectively. HCN content ranged from 8.33 to 28.8 mg HCN/kg dry weight basis.

Fernando and Milagro (2007) analysed processed fresh cassava roots for lipid within five hours after harvest. The result showed the total lipid content as 0.25% fresh weight, the lipid mixture obtained was complex. The work was intended to be the starting point of further research on cassava lipids upon subjecting the roots to conditions leading to its preservation.

Guillermo and Mauricio (2006) evaluated the chemical composition and cyanide concentration in the foliage of four cassava cultivars (M Col 113, M Col 22, M Col 1684, CM 342-170) at four plant ages (6, 8, 10 and 12 months); including some observations on the tannin content of dried foliage. In most cases, the results showed that foliage from 6 to 12 month-old plants contained 25 to 30% dry matter, and dried foliage had 13 to 20% crude protein and 16 to 20% crude fibre. Crude protein and crude fibre were the two chemical constituents which varied the most with plant age. Sun-dried foliage samples had consistently lower tannin content than the corresponding oven-dried samples (Guillermo and Mauricio, 2006).

Carmen *et al*. (2007) investigated the nutrient contents of cassava leaves meal (CLM) from five cultivars at three ages of the plant in order to select the cultivars and ages with superior levels of these nutrients. When the plants were 12 months old, the highest levels of crude protein (CP), β-carotene, iron, magnesium, phosphorus and sulphur were determined. The IAC 289-70 cassava variety showed the highest levels of magnesium, as well as considerable contents of CP, β-carotene, iron, zinc and sulphur.

In Brazil, cassava leaf meal (CLM) has been used to strive against undernourishment because it is a high source of vitamins and minerals. However, the wide variation in the chemical composition of the different cultivars, as well as their anti-nutritional substances may be a restriction to their uses. The levels of some anti-nutrients in CLM from five cultivars at three

ages of the plant (TAP) were investigated, in order to select the cultivars and plant ages that would be more appropriate for human consumption (Carmen *et al*., 2007). The lowest content of anti-nutrients were observed in the 12-month old plants, except for nitrate and hemagglutinin from which the lowest levels were measred the 17-month old ones. The cultivar IAC 289-70 had the lowest anti-nutrient levels, except for saponin and oxalate. Thus, IAC 289-70 at 12 months of age is the most appropriate for human consumption.

A peculiarity in cassava tuberous root starch is the presence of high amylopectin content (70%) (Smith, 2000). Like the tuber flesh, the peel is deficient in fat, minerals and vitamins, and would be useful mainly as an energy source. In contrast to the tuber, cassava leaf is rich in protein (25%), ash (9%), fat (12.7%) and fiber (11%). The high level of crude fibre of cassava leaf or foliage (leaves and stems) makes it a particularly useful source of roughage for ruminants (Smith, 2000).

Comparative studies carried out by Awoyinka *et al*. (2005) on the total cyanide content of cassava leaves and that of conventional vegetable (*Amaranthus*), showed the ash content as 4.6 - 6.4% in cassava leaf samples but 13.1% dry weight in *Amaranthus*. Dietary fibre was found to be very high in all the samples (26.9 - 39% dry weight).

The drying effect of varying light frequencies on the proximate composition of cassava was investigated by Kolawole *et al*. (2009). Drying was carried out using a solar fabrication. The results of the various physicochemical parameters revealed significant difference between the mean temperatures of the colour frequencies compared with the control ($P < 0.05$). The colour black recorded the highest moisture content (67.0%), while deep purple had the lowest (57.0%). The results of the proximate composition showed that black had the highest percentage

carbohydrate (92.64%) and white had the highest vitamin C content compared to the control. Also deep orange, deep yellow and light purple had the highest crude fat (3.03%), crude fibre (0.72%) and ash (2.79%) respectively compared to the control.

Oyewole and Ogundele (2001) studied the effect of length of fermentation on the functional characteristics of fermented cassava 'fufu' obtained from the cassava clones 30572. The result of the investigation revealed that the yield of 'fufu', the bulk density and the dispersibility increased with increasing period of fermentation. When subjected to sensory evaluation, the preference of the panelists for the characteristic 'fufu' texture and odour increased with increased length of fermentation. Except for the 'fufu' made without fermentation (0 h), there was no significant difference in the colour of the 'fufu' fermented for different length of time. For all the attributes rated (texture, odour, colour, overall acceptability), there was no significant difference between the 'fufu' fermented for 72 hours and 96 hours. A fermentation period of 72 hours was recommended for the production of good quality 'fufu' when using the cassava clone TMS 30572.

An investigation was conducted to determine the quality and consumer preference for ‘lafun’ made from different cassava varieties by Oyewole and Afolami (2001). The cassava varieties which were fermented to produce 'lafun' in this study were three newly introduced varieties (TMS 30572, TME1, TMS 4(2)1425) and one local variety called ’sunikankoniyan’. There was no significant difference in the physico-chemical changes of the cassava varieties as a result of the 96 h fermentation process. The fermentation process increases the total titratable acidity and decreases the total sugars, starch, ash, fat, fibre and protein contents of the root. However, significant reductions in fibre was found with TMS 4(2)1425. There were significant differences

in the cooking characteristics of the fermented flour made from different cassava varieties. The flour from the local variety, 'Isunikankoniyan' gelatinises faster than the new varieties, while the cassava clone TMS 4(2)1425 requires significantly higher heating to gelatinise. Except for the flour of TMS 4(2)1425, there was no significant difference in the viscosity of the cooked cassava flour from the tested varieties. 'Lafun' made from the local variety, 'Isunikankoniyan' and the cassava clone TME 1 were most preferred.

Flours from 31 cassava varieties were evaluated for physicochemical properties and pasting characteristic. The cyanogenic potential (CNp) ranged from 0.58 to 20.0 mg HCN per 100 g of dry weight with the 081/00356 cultivar having the highest value, while 90/00330 had the lowest (Aryee, 2006).

Sègla *et al*. (2009) identified the characteristics of two types of 'lafun' ('chigan lafun' and ordinary 'lafun') produced in Benin. The distinctive characteristics of 'chigan lafun' (the preferred type) were its lower solubility and fibre content and its higher hot paste viscosities compared to ordinary 'lafun'. The two 'lafun' types, were found to be white product with a highly variable pH (4.5-8.8). Both types were rich in carbohydrates (76.0% of starch and 3.3% of crude fibres), poor in proteins (1.0%) and containing fat (0.4%) and ash (1.2%). The swelling power of the lafun flour (expressed by the quantity of water absorbed by 1 g of flour) was 28.9 g water/g for both. 'Lafun' has a variable microbial load with range 104 to 108 cfu/g, made up of *Bacillus spp*. (104-108 cfu/g) and lactic acid bacteria (103-107 cfu/g).

2.7 Hydrolysis of Linamarin by the Endogenous Linamarase Enzyme

Hydrolysis by the endogenous linamarase enzyme is shown to be a reversible reaction facilitated by the growth of microorganisms that subsequently results in the gradual decrease of the pH of the medium from about 6.0 to 3.8. At the initial high pH values, the forward reaction is favoured, but as the pH decreases hydrolysis is impeded due to the fact that the reverse reaction is favoured (Oke, 1989).

Hence, with most processing methods involving hydrolysis, unless it is combined with other methods, it could be extremely difficult to eliminate all the cyanogens. Because of this, boiling, frying, cooking and drying directly are inefficient methods (Oke, 1989). Traditional methods were known to always tend to combine one or two of the efficient methods with the other less efficient ones to give an almost cyanogen-free product (Oke, 1989) .

Umar *et al*. (2006) demonstrated that the cyanogenic glucoside linamarin, and its hydrolytic enzyme linamarase, a beta-glucosidase [EC 3.2.1.21], are known to be compartmentalised in the intact tissues of the cassava. Upon damage to the tissue, the two come together to give glucose and its aglycone moiety; the latter degenerates further under an alkaline/neutral environment to give hydrogen cyanide and ketone.

Cassava accumulates two cyanogenic glucosides, linamarin and lotaustralin. Linamarin accounts for more than 80% of the cassava cyanogenic glucosides (Cereda and Mattos, 1996). It is a ß-glucoside of acetone cyanohydrin and ethyl-methyl-ketone-cyanohydrin. Linamarin ß-linkage can only be broken under high pressure, high temperature and use of mineral acids, while its enzymatic break occurs easily. Linamarase, an endogenous cassava enzyme, can break this ß-

linkage. The enzymatic reaction occurs under optimum conditions at 25ºC and pH 5.5 to 6.0. Linamarin is present in all parts of cassava plant, being more concentrated in the root and leaves. If the enzyme and substrate are joined, a good detoxification can occur. All the cassava plant species are known to contain cyanide. The lethal dose of CN^- is 1 mg/kg of live weight; hence, cassava root classification into toxic and non-toxic depends on the amount of cyanide in the root. Should the cyanide content be high enough to exceed such a dose, the root is regarded as toxic. Values 15 to 400 ppm (mg CN^-/kg of fresh weight) of hydrocyanic acid in cassava roots have been mentioned in literature. However, more frequent values in the interval 30 to 150 ppm have been observed (Cereda and Mattos, 1996).

Linamarin and lotaustralin are ß-glucosides of acetone cyanohydrin and ethyl-methyl-ketone-cyanohydrin respectively. The structure of linamarin is shown in Figure 2.7

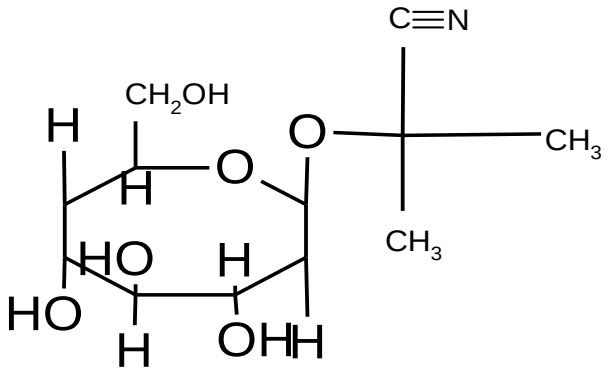


Figure 2.8: Structure of linamarin (Cereda and Mattos, 1996)

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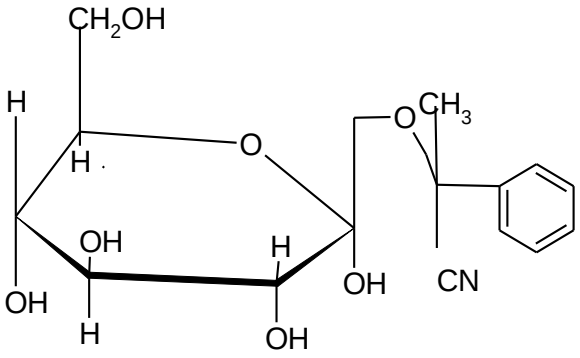
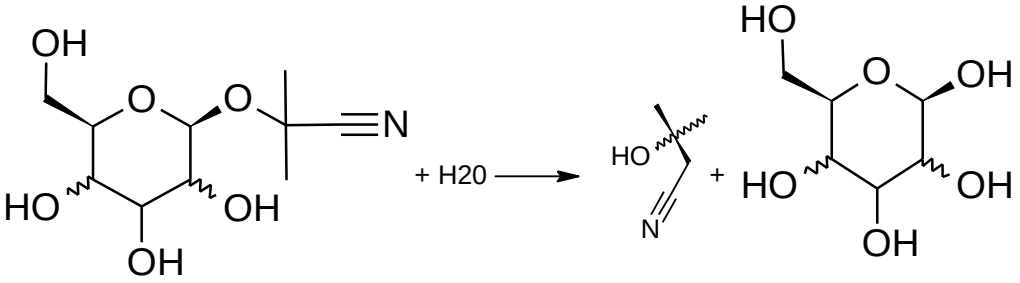


Figure 2.9 Structure of Lotaustralin



linamarin cyanohydrin B-D-glucose

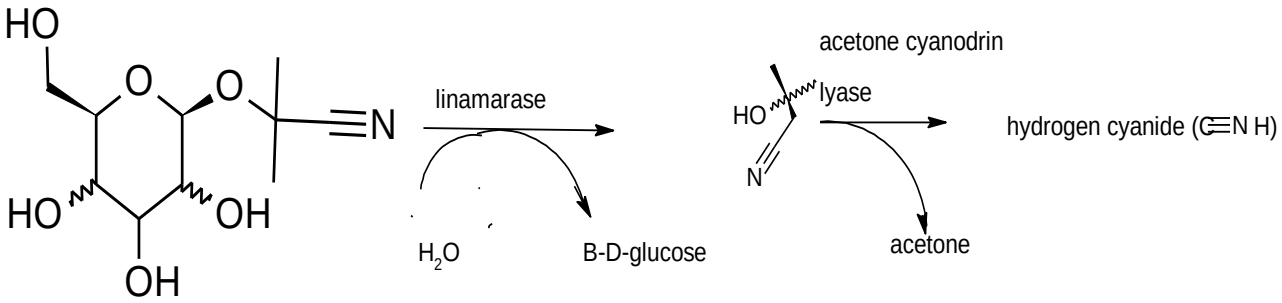


Figure 2.10: Degredation of linamarin (Capsi *et al*., 2010)

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials and Reagents

All the reagents used for the experimental work were of Analar grade. The reagents used are highlighted in the Appendix I

3.2 The Study Area (Evolution of Niger State)

In the political evolution of Nigeria, Niger State, a predominantly rural, and among the least industrialised states in the federation, belongs to the second generation of states.The State is located between latitude $8^{o}20'$ N and $11^{o}30'$N and between longitude $3^{o}30'$ E and $7^{o}20'$ E thus giving the geographical location of the State within the middle belt or what is now referred to as the North Central part of Nigeria.

At its creation, Niger State was made up of seven local government Areas (LGAs) but through subsequent administrative reforms, this number rose to ten in 1987 and nineteen in 1991.

With this number of Local Government Areas and most importantly with the inclusion of Borgu and Agwara as part of Niger State, the State has the highest land area in Nigeria accounting for about 9% (about 76,000 km^2) of the country's total land area (8.44×10^5 km^2).

Niger State experiences the hottest period of the year in March and April just before the onset of the first rains and throughout the year, the daily maximum temperature is as high as 32^{O}C. This temperature however, drops sharply during the peak of rainy season (from July to early September).

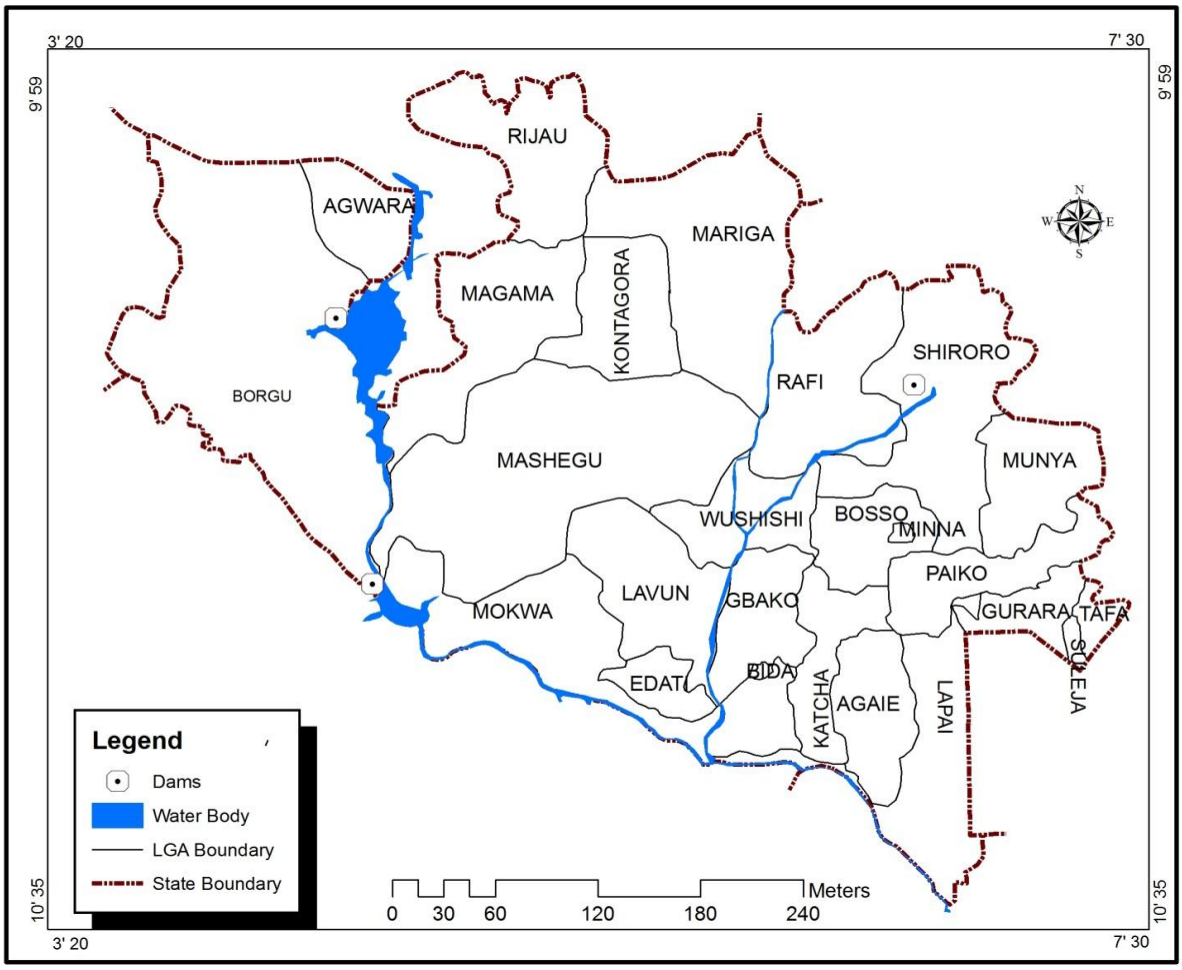


Figure 3.1: The political map of Niger State

The rainy season lasts for seven months in the southern part of the state, but decreases to six months in the northern part. As a result of this, there is a general decrease in the total annual rainfall from the eastern part (1200 mm) to western part (about 1015 mm) of the state (Baba, 1993).

Generally however, there is a reasonably reliable rainfall all over the territory capable of supporting large scale mechanized farming that will encompass large production of such crops as maize, sugarcane, fruits, soybeans, guinea corn, yams and groundnuts.

Most soils in Niger State are predominantly the ferruginous types with deep red colour and some, enriched with clay sub soils although within floodplains, the soils are greyish (and sometimes whitish) in colour. These latter soils are water logged due to their high silt content. The landscape of the state is adorned with giant *Termitaria* (anthills) which are particularly numerous in Mokwa, Kontongora and Bida areas (Baba, 1993).

According to the 1991 national head count, Niger State had a total population of 2,482,367 people and 52% of this figure (1,290,720) was males while 48% (1,191,647) were females. From this figures, the average population density of the state is very low about 33 persons per square kilometres) and indeed, evidence in such large Local Government Areas like Borgu, Shiroro and Wushishi suggests that the state is endowed with expanses of large land resources waiting to be developed by agricultural activities and industrialisation. The growth of cassava and its varied products is significant in boosting the socio-economic life of the State. So, this study has chosen Niger State as the study area for cultivation of cassava.

3.3 Socio-ecological Mapping of the Study Area

A survey of the areas of study in the state was made in order to delineate them into their appropriate geo-agricultural zones. Such important features as the climate, relief and rainfall of the areas of study were taken into consideration and the regional differences as well as human efforts that have been made towards the exploitation of the potentials of improved cassava products were identified and the differences were appropriately taken into consideration. The study considered Bida, Wushishi and Kontagora areas as the three towns where a 80 X 100 m^2,

90 X 90 m^2 and 80 X 100 m^2 land mass respectively was used for planting each variety of cassava separately in each of the study area. These towns were chosen based on the prevalence of the cassava products consumption by the populace of these areas compared to other major towns like Minna, Mokwa and New Bussa in the State. Each town covered four villages (sites) which served as the sampling points.

3.4 Sampling Scheme and Samples

3.4.1 Preparations of cassava samples

The samples of the cassava varieties planted for the study consist of three improved varieties (TME419, TMS92/0326 and L30572) and six local varieties (Karimugi, Kpace Bokun, Kpace Dzuru, Baba Iya, Dan Warri and Wahabi).

The stems of the 9 species of cassava sourced from Niger State Agricultural Development Project (NGADP), and some from local sources were planted in the three selected towns of Niger State. After maturity (12 to 13 months old) the harvest was done from the various farming sites, and each variety was processed into 'gari' and 'fufu' products through natural and microbial fermentations separately. 'Lafun' products on the other hand, were produced neither through microbial nor natural fermentation, but only peeled, dried and grinded to flour. All these products were produced in triplicates. The resultant cassava products samples (n = 189) were stored in polythene bags for analyses.

3.4.2 Sampling of soils where the cassava varieties were planted

Soils of the three selected towns (Suleja, Kotongora and Bida) on which the nine varieties of cassava were grown prior to planting were sampled. Each town comprised of four sites each 80×100 m^2 which were 3 to 4 kilometres apart, depending on the distances between the surrounding villages. Suleja town consisted of Kpasson, Gwam, Jita and Shipagbe sites. Bunigi,

Wushishi, Maito and Kawo sites constituted the Kontagora town while Batavovogi, Masaga, Kupafu and Kuchita sites made up Bida sampling town.

Each site was divided into four (20 × 25 m^2), from each quadrant five samples were collected in a diagonal basis in triplicate for the topsoil and also subsoil. Composite samples of the soils of each quadrant were obtained; n = 32 for each town. The samples were dried and then sieved using a 2 mm sieve, and stored in polythene bags prior to analyses.

3.4 3 Method of processiing the 'fufu'

The freshly peeled roots were soaked in water for 3 days so as to absorb water and get fermented and soft. After fermentation, the water was drained off, most of the fibre were removed and the roots were pounded in a wooden mortar, until a soft mash was formed. Excess water was extracted from the mash by placing heavy objects such as rocks on top of the sacks containing the 'fufu'.

3.4.4 Method of processing the 'gari'

The fresh roots were peeled and grated, after which the grated pulp was put in sacks (polypropylene) and the sacks placed under heavy stones for 4 days to expel excess liquid from the pulp while it was fermenting. The dewatered and fermented lumps of pulp were then crumbled by hand, and most of the fibrous matter were removed. The remaining mass was sieved with traditional sieves of iron mesh. After being sieved, the fine pulp was then roasted in an iron pan over fire to get the pulp roasted.This resulted in a finished white lumpy product called 'gari'.

3.4.5 Method of procssing the 'lafun'

'Lafun' in Nigeria, 'cossettes' in Zaire and Rwanda, 'kanyanga' and 'mapanga' in Malawi and 'makopa' in Tanzania was processed by peeling the fresh root of cassava, followed by grinding and then draining the extracts of the pulp under heavy weight. Sun-drying of the pulp for 5 days until dried to yield 'lafun' The dried crumbs would then be milled into flour.

3.4.6 Fermentation of cassava mash

At the commencement of fermentation of each of the pulp to be made into 'gari' and 'fufu' products, 25 cm^3 of the inoculants of *Saccharomyaces cerevisea* and *Lactobacillus bulgaricus* was seperately administered into each 500 g mash under disinfected conditions. As soon as this was done, the pulp was allowed to ferment along with another set of other pulps of the same mass and of the same cassava varieties that were not inoculated, for four days. Meanwhle, mash to be made to 'lafun' products were neither fermented nor inoculated.

Each of the intermediates ('gari', 'fufu, or 'lafun') was separately ground using a mortar and pestle to obtain powdery samples. They were then stored in polythene bags for further analysis. As earlier mentioned triplicate samples of each cassava products from the different varieties was collected. This was also done for the inoculated and fermented products without inoculants. Due regard was given to the geo-agricultural distributions of the data obtained for the cassava products and cassava varieties, with a view to carrying out comparative analyses.

3.5 Analyses of Soil

Both the physical and the chemical parameters of the soil samples collected from Bida, Suleja and Kontagora towms, were carried out using modern and appropriate mthods.

3.5.1 Particle size analysis (Bouyoucos hydrometer method)

A 50 g portion of the 2 mm sieved soil sample was weiged into a conical flask. Then 100 cm^3 of calgon was added and left for 30 minutes. The soil suspension wasthen transfered to a dispersion cup and stirred with a mechanical stirrer for 15 minuted.The mixture was transfered to a 1.0 dm^3 capacity measuring cylinder and distilled water to make up to the mark. The soil suspension was then stirred with a glass stirring rod for 2 minutes to make sure that the particles are in suspension. A hydrometer was inserted and the reading taken after 40 seconds. A thermometer was immediately inserted and the reading taken. The set up was left undisturbed on a stable surface.After 2 h a thermometer and a hydrometer were inserted and the readings taken.

A blank was prepared by adding 100 cm^3 calgon into a 1.0 dm^3 measuring cylinder and made up to the mark with distilled water. The readings of the thermometer and the hydrometer were taken at 40 seconds and 2 h immediately after or before taking that of the sample.

Temperature correction

For every 1 ^oC above 20 ^oC, 0.36 was added to the hydrometer reading and for every 1 ^oC below 20 ^oC, 0.36 was substracted from the hydrometer reading

$$\% \text{ Silt + Clay} = \frac{(S1 - B1) + (ST1 - 20\ ^oC) \times 0.36 \times 100}{50} \quad (3.1)$$

$$\% \text{ Clay} = \frac{(S2 - B2) + (ST2 - 20\ ^oC) \times 0.36 \times 100}{50} \quad (3.2)$$

$$\% \text{ Sand} = 100 - \% \text{ Silt + Clay} \quad (3.3)$$

$$\% \text{ Silt} = \% \text{ Silt + Clay} - \% \text{ Clay} \quad (3.4)$$

S1= Sample Hydrometer Reading at 40 sec,

ST1 = Sample Thermometer Reading at 40 sec,

S2 = Sample Hydrometer Reading at 2 h,

ST2 = Sample Thermometer Reading at 2 h,

B1 = Blank Hydrometer Reading at 40 sec,

BT1 = Blank Thermometer Reading at 40 sec,

B2 = Blank Hydrometer Reading at 2 h,

BT2 = Blank Thermometer Reading at 2 h.

3.5.2 Determination of soil pH

A 20 g amount of the air – dried 2 mm sieved soil was weighed into a beaker in duplicate. Into one set-up, 50 cm^3 distilled water was added and 50 cm^3 0.01 M $CaCl_2$ or KCl was added into the other. The two mixtures were stirred for 1 minute and left to stand for 15 minutes. Each set-up was stirred again for 1 minute and left for 15 minutes. A pH meter was standardized using buffer solutions, and its electrode inserted into each of the supernatant liquid, following which the reading was taken.

3.5.3 Determination of organic carbon and organic matter (Walky – Black method)

A 1 g amount of the air – dried 0.5 mm sieved soil collected from Kontagora, Bida or Suleja town.was weighed into 250 cm^3 conical flask. 5 cm^3 of 1M $K_2Cr_2O_7$ was added and the flask swirled gently to disperse the soil in the sample. A 10 cm^3 portion of concentrated H_2SO_4 was

added and the mixture thoroughly mixed. The mixture was allowed to stand preferably on an asbestos pad for 30 min to cool down. Into the mixture, 100 cm^3 of distilled water was added and subsequently 3 to 5 drops of the indicator solution (mixture of 5 g barium chloride, $BaCl.2H_2O$, and 0.3 g barium diphenylamine sulphonate dissolved in water). The resulting mixture was titrated with 0.2 M $(NH_4)_2FeSO_4$. A 5 cm^3 portion of H_3PO_4 was added to the mixture if the indicator to be used is o-phenathroline indicator in order to sharpen the end point A blank without the soil sample was prepared.

$$\text{Organic carbon (g kg}^{-1}\text{ soil)} = \frac{(BT - ST) \times N \times 10}{W} \quad (3.5)$$

BT = Blank Titre Value

ST = Sample Titre value

N = Normality of $(NH_4)_2FeSO_4$

W= Weight of Soil Sample

$$\text{N can be obtained by: } \frac{cm^3 \text{ of } K_2Cr_2O_7 \text{ (5 cm}^3\text{)}}{BT} \quad (3.6)$$

$$\text{Soil organic matter} = \text{organic carbon} \times 1.72 \quad (3.7)$$

3.5.4 Determination of available phosphorus (Bray PI or dilute acid – fluoride extraction Method)

A 2 g portion of the air – dried 2 mm sieved soil sample obtained from Kontagora, Bida or Suleja town was weighed into an extraction bottle. A 15 cm^3 portion of the extracting solution was added and shaken for 1minute.The suspention was filtered through a Whatman No. 42 filter

paper or centrifuged at 2000 revolutions per minute for 15 minutes and supernatant solution decanted into a clean flask. The phosphorus level in the solution was then determined calorimetrically.

A 2 cm^3 amount of the extract was measured from the supernatant solution above, and 0, 1, 2, 3, 4 and 5 mg dm^{-3} P of the working Standard added. About 5 cm^3 of distilled water was then added to each of the set. A 2 cm^3 aliquot of the ammonium molybdate solution was added and mixed properly. To each of them 1 cm^3 of $SnCl_2.2H_2O$ solution was added and mixed thoroughly. After 5 minutes, but not later than 20 minutes the absorbances at 600 nm wavelength were measured for each set-up using spectophotometer (model: 210 GDP BUCK). The calibration curve was prepared from absorbance values obtained for the working standards, and the P in the soil samples from from Kontagora, Bida and Suleja towns determined.

If Y is the mg dm^{-3} P obtained for the sample from the calibration curve, then P mg kg^{-1} in the soil is P in soil (mg kg^{-1}) = Y × 35 (3.8).

3.5.5 Determination of exchageable bases (NA^+, K^+, Ca^{2+} and Mg^{2+})

3.5.5a Extraction of exchageable bases from the soil

A 10 g portion of the air – dried 2 mm sieved soil was weighed into a conical flask. Exactly 40 cm^3 of NH_4OAC (made up of 70 cm^3 of ammonia solution and 57 cm^3 of acetic acid, 99.5%) was added. The flask was gently swirled and covered, it then left to stand overnight.The suspension was transferd into a Buckner funnel that has been lined with moistened Whatman No. 42 filter paper. This was connected to the suction pump that had been fitted with suction flask. The soil suspension was leached with more NH_4OAC until the 100 cm^3 mark was reached.

3.5.5b Determination of Na^+ and K^+ in the extract

The flame photometer was initially calibrated with 0 and 10 $mgdm^{-3}$ standards. The readings of the 2, 4, 6 and 8 mgL^{-1} standards were taken, followed by the readings of the soil samples obtained from Kontagora, Bida and Suleja towns. The standard readings were retrogressed against the concentration to get a straight line graph, Y = bx. Sample concentrations of the samples were determined from the equation:

$$\text{K or Na } (mg100g^{-1} \text{ soil}) = \frac{C \times L \times 100}{1000 \times W} \quad (3.9)$$

$$\text{K or Na } (mgkg^{-1} \text{ soil}) = \frac{mg100\ g^{-1}}{E} \quad (3.10)$$

X = weight of soil

C = sample concentration

L = ml of leachate coolected

E = Equivalent weight of K or Na

3.6 Chemical Analysis of the Cassava Products (Inoculated and Uninoculated)

The chemical parameters which include crude protein (CP), total carbohydrate, crude fibre (CF), moisture content, nitrogen free extract (NFE), ash content, crude fat (the proximate analysis), presence of some anti-nutritional factors and other toxic substances (phytates, saponins and oxalates), micro (zinc and iron) and macro (magnesium, potassium, sodium, calcium and phosphorus) minerals were analysed in the cassava products by ISO and AOAC official methods of analysis.

3.6.1 Determination of moisture content of the cassava products using evaporation method

A 3.00 g portion of the ground cassava product ('gari', 'lafun' or 'fufu') that were allowed to pass through 1mm screen was weighed in triplicates into covered Petri dishes in a microwave oven and dried to constant weights at 100^0C (Julian, 1999; AOAC, 2000). The moisture content of each of the cassava products from each of the varieties (TME419, TMS92/0326, L30572, Karimugi, Kpace Bokun, Kpace Dzuru, Baba Iya, Dan Warri and Wahabi), for those inoculated and those not during processing were determined by:

$$\% \text{ Moisture (wt/wt)} = \frac{\text{(wt of wet sample - wt of dry sample)}}{\text{wt of wet sample}} \times 100 \qquad (3.11)$$

wt = weight

3.6.2 Determination of total dry matter (TDM) and total organic matter (TOM) of the cassava products

After drying each of the cassava products (inoculated and uninoculated), the TDM (%) was obtained by subtracting the moisture content earlier determined for each sample of the products from 100.

$$\text{i.e. TDM (\%)} = 100 - \% \text{ moisture} \qquad (3.12)$$

The total organic matter was determined by ashing each of the samples of the cassava products inoculated and uninoculated and subtracting the % ash from the % TDM.

$$\% \text{ organic matter (\% OM)} = \frac{TDM\ (\%) - ash\%}{TDM\ (\%)} \times 100 \qquad (3.13)$$

3.6.3 Determination of ash content of the cassava products

A 0.5 g amount of each of the 'fufu', 'gari' or 'lafun was accurately weighed in crucibles and incinerated in a muffle furnace (Gallenkamp Ltd) at 650^{o}C for at least 6 h after pre-ashing. The sample was then cooled in a desiccator and re-weighed.

$$\text{Ash (\% w/w)} = \frac{weight\ of\ crucible + TDM - Weight\ of\ crucible + TIM}{TDM}\ x\ 100 \qquad (3.14)$$

TIM = Total inorganic matter (AOAC, 2000).

3.6.4 Determination of crude fat in the cassava products using the Ministry of Agriculture Fish Food Method

Samples of the cassava products used for the dry mater determinations were collected into petri dishes to determine the crude fat. Exactly1.0g triplicate samples of each of 'gari', 'fufu' or'lafun' was weighed accurately into a thimble and placed in a soxhlet apparatus that was well stocked with cotton wool. The apparatus was placed in a dry solvent flask containing 40-60^{o}C petroleum ether positioned beneath it. The apparatus was connected to the condenser. The extraction was carried out for at least 6 h or until the solvent in the soxhlet compartment was colourless. The filter papers with the samples were removed after the ether might have been reclaimed using the apparatus. They were dried in a microwave oven for 30 minutes at 100^{o}C. Each set-up was then cooled in desiccators and weighed (Ministry of Agric Fish Food, 1973).

Calculation

$$\%\text{crude fat (DM)} = \frac{Weight\ of\ \ filter\ paper\ TDM - weight\ of\ \ filter\ paper(TDM - w)}{TDM}\ x\ 100 \qquad (3.15)$$

w = weight of the fat

3.6.5 Determination of crude fibre in the 'fufu', 'gari' and 'lafun' products

The AOAC official method 962.06 was employed with modifications in order to determine the crude fibre contents of the 'fufu', 'gari' and 'lafun' products samples.

An amount of 1g of each of the fat free samples was weighed in triplicate, and transferred in each case into a distillation flask containing 200 cm^3 of 0.1275 $moldm^{-3}$ H_2SO_4 solution. The distillation flask with its content was connected to a condenser and the meals ('fufu', 'gari' or'lafun') digested for 30 minutes by boiling. Distilled water was used to wash down particles adhering to the sides of the flask. The samples were then filtered through a No 541 Whatman paper in a Buchner funnel using suction or through a filtering cloth in a fluted funnel washing with boiling water. The residue was transferred into a beaker containing a hot 200 cm^3 of 0.313 $moldm^{-3}$ NaOH solution and boiled for 30 minutes. The residue was finally washed with 98% Analar grade ethanol solution. The residue was dried overnight at 100^oC in a microwave oven, cooled in desiccators and weighed. The meals were ashed at 600^oC for 3 h or until it is carbon free, it was then cooled and weighed (AOAC, 2000).

$$\text{Crude fibre (\% of fat free DM)} = \frac{a-b}{TDM} \text{ X}100 \qquad (3.16)$$

a = weight of crucible + weight of dried residue, b = weight of crucible + ashed residue

3.6.6 Determination of the nitrogen free extract (NFE) in each of the cassava products

This was done by calculating the difference using the formula:

$$\text{NFE (on dm basis)} = 100 - (\%\ CP + \%\ CF + \%\ CF^i + \%\ Ash) \qquad (3.17)$$

CP = crude protein, CF = crude fibre, CF^i = crude fat.

3.6.7 Determination of carbohydrate in the 'gari', 'fufu' and 'lafun' of cassava products

The carbohydrate content of **'**gari', 'fufu' and 'lafun' products was estimated by calculating the difference in equation 3.8. In this case, the amount of proteins (P), water (W), fat (F) and Ash (A) were subtracted from 100 to obtain the total carbohydrate content of the meals of 'fufu', 'gari' and 'lafun' **(**Craig, 2004).

total carbohydrate (% on dm basis) = 100 – (P+W+F+A) (3.18)

3.6.8 Determination of crude protein of the cassava products using the Micro Kjeldahl digestion and distillation methods

The official method of food analysis by Association of Analytical Chemists with suitable modifications by Oyeleke (1984) was adopted for the determination of the total nitrogen contents of the samples of 'gari', 'fufu' and 'lafun'.

A 0.1 g amount of each of the sample of 'gari', 'fufu' or'lafun' products was accurately weighed into a digestion flask, then 1 g of potassium sulphate, 0.07 g of mercuric oxide and 10 cm^3 of concentrated H_2SO_4 were added to the sample in a tube. The flask was then heated gently until frothing subsided, boiling continued until the solution became either colourless or light yellow. The mixture was transferred into a 100 cm^3 volumetric flask after cooling, and made up to the mark with distilled water. The content of the flask was transferred into a distillation flask and a 2.5 cm^3 of 4% sodium sulphide solution added, then the solution thoroughly mixed. A small piece of pumice was added to prevent bumping, and 8 cm^3 of 40% sodium hydroxide solution added. The mixture was poued into a condenser and distilled, the distillate was allowed to be poured into a 100 cm^3 conical flask containing 5 cm^3 of 2% boric acid solution; this was mixed

with 3-4 drops of 0.2% bromocrysol or 0.1% methyl red in ethanol, and mixed with the indicator. The delivery tube was allowed to dip into the solution in the conical flask to collect the distilled ammonia until the pink colour of the mixed indicator changed to green. The distillate was collected for two minutes and then titrated against a 0.014 moldm^{-3} standard HCl solution (Liliana *et al*., 2008).

$$\% \text{ T N} = \frac{(Sample \text{ titre - Blank titre}) \times \text{concn of HCl} \times 0.14007 \times V_1}{WV_2} \times 100 \quad (3.19)$$

$$\% \text{ T N} = \frac{(Sample \text{ titre - Blank titre}) \times \text{concn of HCl} \times 14.007 \times V_1}{WV_2} \quad (3.20)$$

TN = total nitrogen in the sample

Or this can be expressed as:

%T N= (T-B) X concentration of HCl X $0.14007V_1/V_{2\,X}$ sample weight (3.21)

T= sample titre; B = blank titre;

V_1 = volume made up; V_2 = aliquot taken for distillation;

W = sample weight.

% crude protein = % total nitrogen X 6.25

Or crude protein = % T N x 5.46 for the cassava samples.

The percentage recovery was determined by using a 5 or 10 cm^3 2% $(NH_4)_2SO_4$ that have been dried overnight at 105^oC and subjected to the same treatments as the samples. This was used to test the reliability of the set up.

$$\% \text{ recovery} = \frac{Nitrogen\,obtained}{Theoretical\,value} \times 100 \qquad (3.22)$$

(Harris, 1970; AOAC, 2000; Oyeleke, 1984)

3.6.9 Perchloric acid digestion (wet oxidation) of samples for P, Ca, Mg, Fe, Mn, Zn, Cu, K and other minerals determinations

Triplicates samples of 0.5 g ground cassava products ('fufu', 'gari' or 'lafun') that had been oven dried at 60^oC was weighed into 125 cm^3 Erlenmeyer flasks which had been previously washed with acid (HNO_3) and distilled water. A 4 cm^3 volume of 60% or 70% perchloric, 25 cm^3 concentrated HNO_3 and 2 cm^3 concentrated H_2SO_4 were added to each sample of 'fufu', 'gari' or 'lafun', the mixture was then heated on a hot plate under an acid fume hood until white fumes appears or until colorless or clear yellow solutions was obtained. The samples were cooled and 40 - 50 cm^3 of deionised water added and then further heated to boiling. Each of the sample was finally cooled and filtered into a 100 cm^3 volumetric flasks (using a Whatman filter paper) and made up to the mark. The solutions were then stored in plastic containers for further determinations (IITA, 1979).

3.6.10 Phosphorus determination using the AOAC Vanado-Molybdate official method

i. A molybdovanadate reagent was prepared every three days as the reagent is known for not stable for a long time. The reagent was prepared by dissolving 5.0 g of ammonium molybdate tetrahydrate $[(NH_4)_6Mo_7O_{24}\cdot 4H_2O]$ in 50 cm^3 of hot water and then cooled. A 0.25 g

amount of the ammonium metavanadate was dissolved in 37.5 cm^3 of hot water and then allowed to cool. A 26.5 cm^3 70% perchloric acid or 37.5 cm^3 of concentrated HNO_3 was gradually added to the mixture with stirring. The content was made up to the mark of a 250 cm^3 volumetric flask

ii. The standard phosphorus solution was prepared by dissolving 0.1220 g of KH_2PO_4 (previously dried for 1 h at 120^0 C) in 1 dm^3 deionised water (1cm^3 = 0.05 mg P). This was stored in a plastic container for further use.

iii . Calibration curve for the phosphorus was prepared by pipetting 0, 1, 2, 3, 4 and 5 cm^3 of the working phosphorus standard into 50 cm^3 volumetric flasks. A 20 cm^3 amount of the molybdovanadate solution was then added to each flask and then made up to the mark. This was left for at least 1 hour for maximum colour development. These solutions should contain 0, 50, 100, 200 and 250 µg P respectively.

Phosphorus was determined at 420 nm colorimetrically. A calibration graph was plotted by plotting the absorptions of the solutions against the phosphorus concentrations.

$$\% \text{ P in the samples} = \frac{Sample\ reading\ on\ the\ graph\ (\mu g)\ x\ dilution\ factor}{10{,}000\ x\ weight\ of\ sample.} \qquad (3.23)$$

(AOAC, 1970).

3.6.11 Determination of potassium and sodium (FES) method

A 1.9103 g crystals of potassium chloride and 2.5435 g of sodium chloride was accurately weighed and dissolved in 1000 cm^3 volumetric flasks to serve as 1000 ppm stock solutions for potassium and sodium respectively.

Appropriate serial dilutions of these stocks were prepared as working standards and run in a flame photometer (Model: JENWAY PFP 7) to determine the concentrations of the elements in the 'fufu', 'gari' and 'lafun'. Their readings were used to plot calibration graphs for these elements. The blanks for these samples were similarly determined to allow for blank corrections.

The samples of the cassava products ('fufu', 'gari' and 'lafun') obtained from the wet digestion were similarly run to obtain the concentrations from the respective calibration graphs. The readings obtained gave the concentrations in parts per million (ppm).

3.6.12 Preparation of standards for the determination of Ca, Mg, Zn, Fe Cu and Mn in 'fufu', 'gari' and 'lafun', using atomic absorption spectrophotometric method

A 2.4973 g of $CaCO_3$ was accurately weighed into a volumetric flask and dissolved in about 20 cm^3 of 1 $moldm^{-3}$ HCl solution, this was diluted to 1000 cm^3 with deionised water in 1 dm^3 volumetric flask and then transferred into a polypropylene bottle.

A 3.9160 g of $MgCl_2.6H_2O$ was dissolved in enough amount of deionised water and made up to the mark in 1 dm^3 volumetric flask.

Also, a 1.2450 g ZnO was dissolved in 25 cm^3 of a 5.0 $moldm^{-3}$ HCl, and made up to the mark in 1 dm^3 volumetric flask with deionised water and stored in a polypropylene bottle.

A 3.963 g $CuSO_4.4H_2O$ was accurately weighed and dissolved in 25 cm^3 of deionised water and then 1-2 cm^3 of concentrated H_2SO_4 added. The solution was made up to 1000 cm^3 in 1 dm^3 volumetric flask and kept in a polypropylene bottle.

A 1.00 g cadmium metal was dissolved in 50 cm^3 of concentrated HCl. and 2 cm^3 of concentrated HNO_3 was added. This was diluted to 1 dm^3 in a dm^3 volumetric flask with deionised water and stored in a polypropylene bottle.

A 3.6077g of manganese (II) chloride ($MnCl_2.4H_2O$) was dissolved in 50 cm^3 HCl, and diluted to 1 dm^3 in a volumetric flask with deionised water, this was stored in a well capped polypropylene bottle. The solutions prepared above were used as stocks of 1000 ppm for each of the metals and appropriate serial dilutions were made for the standard solution of each metal determined.

3.6.13a Determination of cyanides in the samples (The alkaline Picrate method)

A 1.0 g of the cassava products samples was accurately weighed and placed in a 200 cm^3 conical flask and 5.0 cm^3 portion of a 0.1 $moldm^{-3}$ sodium phosphate solution added.

The extracts from the samples of the cassava products were stored in plastic containers until ready for cyanide determination. The Alkaline Picrate Method was used to determine the cyanide content by the use of a spectrophotometer at 490 nm.

3.6.13b Preparation of standard plot for cyanide determination

A stock solution of KCN was prepared by dissolving 0.004 g of dry KCN in 100 cm^3 of distilled water in a volumetric flask (1 cm^3 of the solution contains 16 µg CN^-).

Ten tightly-stoppered test tubes containing 15cm^3 aliquots of the stock of KCN solution with concentration range 0.8-8.0 µg CN^- were carefully set up. Each tube was made up to 2 cm^3 with distilled water and to each tube, 4 cm^3 of the alkaline picrate solution obtained by the dissolution of 6.25 g of an anhydrous Na_2CO_3 and 0.500 g of picric acid dissolved in 250 cm^3 volumetric flask with distilled water. The whole set up was then boiled in a water bath set at 95^oC. The contents of the tubes were used to determine cyanide at 490 nm using spectrophotometer (model:

JENWAY 6310). The values obtained were used to plot the standard graph for the cyanide determination in the samples of 'fufu', 'gari' and 'lafun' products.

The protocol table below was used for the preparation of the standards.

3.6.13c Determination of total cyanide in the samples

Exactly 1.0 cm^3 of the extract of each sample of 'fufu', 'gari' or 'lafun' was pipetted in triplicate into 15 cm^3 stoppered test tubes and 1.0 cm^3 of 0.1 $moldm^{-3}$ NaOH solution added. The tubes were kept for 30 minutes for the hydrolysis of the extracted cyanogenic glycosides. The librated CN^- was estimated as described from the above standards and the results were determined from the standard graph **(**Ikediobi *et al.*, 1980).

3.6.14 Determination of phytates using anion exchange method

By using 2.00 g of each sample of cassava products ('fufu', 'gari' or'lafun') placed in a 125 cm^3 Erlenmeyer flask, a 40 cm^3 2.4% HCl was added to the flask and covered. The mixture was then shaken vigorously for three hours at room temperature. While this was done, the column was prepared by adding water slurry of the anion exchanger AG1-$_{X4,}$ 100- 200 mesh chloride form to 3 cm^3 H_2O in a mounted column. After the formation of the bed, the column was washed with 0.7 $moldm^{-3}$ NaCl and finally with 15 cm^3 of H_2O. The test solution was removed from the shaker and filtered with vacuum through Whatman filter paper (if refrigerated, the solution is stable for at least one week).

A blank was prepared by mixing 1 cm^3 of 2.4% HCl, 1 cm^3 Na_2EDTA (0.11$moldm^{-3}$) and 1cm^3 NaOH (0.75 $moldm^{-3}$) reagents. This was diluted to 25 cm^3 with H_2O and then poured into the column.

Table 3.1: Development of standards for cyanide determination

Test tube no.	1	2	3	4	5	6	7	8	9	10
Stock (cm^3)	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
H_2O (cm^3)	1.95	1.90	1.85	1.80	1.75	1.70	1.65	1.60	1.55	1.50
Picrate (cm^3)	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
CN^- (µg)	0.8	1.6	2.4	3.2	4.0	4.8	5.6	6.4	7.2	8.0

A 2.0 cm^3 amount of the filtrate was pipetted into 50 cm^3 glass stoppered volumetric flask and 2.0 cm^3 of Na_2EDTA- NaOH reagent was added. This was diluted with distilled water and made up to the mark. This was thoroughly mixed and quantitatively transferred to the column. The eluate was discarded and the sample treated with 15 cm^3 of H_2O and 15 cm^3 of 0.7 $moldm^{-3}$ NaCl solution and in each case, the eluate was discarded. The sample was then treated with 15 cm^3 of 0.7M NaCl solution, after which the eluate was collected in a digestion vessel. A 1.0 cm^3 of concentrated H_2SO_4 and 6.0 cm^3 of concentrated HNO_3 were added to each of the cassava samples and the samples digested under hood on a micro Kjeldahl rack, until active boiling ceases and cloud of thick yellow vapour filled the neck of the flask. The contents were then heated for five more minutes and the flask cooled. About 10 cm^3 of distilled water was added and the mixture transferred to a 50 cm^3 volumetric flask, after which 2 cm^3 of molybdate reagent (2.5% ammonium molybdate in 0.5 $moldm^{-3}$ H_2SO_4 solution) was added. Then 1.0 cm^3 sulphonic acid reagent (0.16 g 1- amino-2-naphthol-4-suphonic acid, 1.92 g Na_2SO_3 and 9.60 g $NaHSO_3$ in a 100 cm^3 volumetric flask) was then added and the mixture agitated thoroughly and left to stand for 15 minutes. The optical activity of the solution was read at 640 nm using a spectrophotometer (model JENWAY 6310).

A phosphate standard solution was prepared by dissolving 0.350 g of dried potassium hydrogen phosphate in 1 dm^3 volumetric flask containing 10 cm^3 of 5 $moldm^{-3}$ H_2SO_4 (1 cm^3 of this solution, contains 80 µg of phosphate).

A 1.0, 3.0 or 5.0 cm^3 of the standard prepared was pipetted into a 50 cm^3 volumetric flasks and 20 cm^3 of distilled water added to each and then mixed thoroughly. A 2 cm^3 portion of the molybdate solution was added to each and mixed thoroughly after which 1 cm^3 of sulphonic acid solution was added to each and mixed thoroughly. After the solutions were made up to marks

with distilled water, they were then left to stand for 15 minutes for full colour development and the optical activities read in spectrophotometer at 640 nm (AOAC, 2000).

$$\text{Phytate, mg/g sample} = \frac{MeanKA\,X\,20}{0.2821} \qquad (3.24)$$

$$= 28.2 \times \%P$$

A = absorbance and Mean K = standard P in µg/A/n (standards).

3.6.15 Determination of saponins of cassava products samples ('gari', 'fufu' and 'lafun')

Saponins were determined gravimetrically using a soxhlet extractor and two different solvents (acetone and methanol). Acetone was used to remove the lipids and interfering pigments in the samples while the methanol was used to extract the saponins.

A 5.00 g portion of the dry ground sample of 'gari', 'fufu' or 'lafun' was weighed, in each case, into a thimble and transferred into the soxhlet extractor chamber fitted with a condenser and a round bottomed flask containing some quantity of acetone. This was refluxed on a hot plate to ensure exhaustive extraction of the lipids and interfering pigments. The solvent was distilled, recovered and taken as the first extraction.

In the second extraction, a pre-weighed round-bottom flask containing methanol was fitted to the extraction chamber containing the first extracted sample, this was refluxed for three hours to exhaustively extract the saponin in the sample of cassava products samples ('gari', 'fufu' and 'lafun').

Table 3.2 Protocol Table for the calculations of K for typical standard plot for phytate determination

Standard (cm^3)	µg P	A	Concentration/A (cm^3)
1	80	0.1805	443.21
3	240	0.516	465.12
5	400	0.852	469.27
mean K			459.27

The solvent was then distilled, recovered and the round-bottomed flask, after cooling, was weighed again to determine the gain in weight. The difference between the initial and final weights of the round bottomed flask was taken as the weight of the saponin in the sample.

% Saponin = weight of saponin x 100 /weight of sample (3.25)

3.6.16 Determination of the oxalic acid contents of the cassava product samples

The determination was accomplished in accordance with the method described by Ranjhan and Gopal (1980) with modifications.

A 1.00 to 2.00 g of the ground samples of the cassava products ('gari', 'fufu' or'lafun'**)** was accurately weighed in beakers and 40 cm^3 of distilled water added in every case. The contents of the beakers were boiled for half an hour with cold water over it. 10 cm^3 of 20% sodium trioxocarbonate (IV) solution was added and the mixture boiled for another half hour. These two heating ensures;

(i) The complete breaking down of the cellular tissues.

(ii) Conversion of all insoluble oxalate salts into soluble sodium oxalate.

(iii) Saponification of all fatty matters.

The liquid extracts were filtered and the residues washed with hot water until the washed water did not show any alkaline reaction. The combined filtrate with the washed water were concentrated to small volumes and allowed to cool. With constant stirring, HCl (1:1) solution would be added dropwisely until heavy precipitate of extraneous matter appears. The extract was carefully filtered in 250 cm^3 volumetric flasks and made up to the marks.

The organic matter was allowed to settle in the flasks by keeping them overnight, and the supernatant liquid was filtered through dry filter paper in dry beakers. Three 50 cm^3 aliquots of the filtrate of each of the sample were taken, each diluted to 100 cm^3, made ammonical with concentrated ammonia solution and reacidified with acetic acid. In the cold medium, 10 cm^3 of a 10% solution of calcium chloride was added to each and the mixture stirred thoroughly to induce precipitation of calcium oxalate. The precipitate was allowed to settle overnight and the clear supernatant liquid was carefully decanted off through Whatman filter paper without much disturbance to the precipitate. The precipitate in each case was dissolved in HCl (1:1) solution. Ammonium hydroxide was added dropwisely to precipitate oxalic acid. The contents was boiled, allowed to settle overnight and the supernatant be discarded. The precipitate was dissolved in 10 cm^3 of 25% (v/v) H_2SO_4 solution. The mixture was warmed to 90^0 C and then titrated against a 0.025 $moldm^{-3}$ $KMnO_4$ solution to determine the oxalic acid.

1 cm^3 of 0.025 $moldm^{-3}$ $KMnO_4$ solution = 0.00225 g anhydrous oxalic acid (3.26)

(Ranjhan and Gopal, 1980).

3.7 Methods of Statistical Analysis

The effects of the methods of processing or preparation of the cassava products and variety on the nutritional and anti-nutritional constituents was analysed using statistical softwares. Both completely randomized block (CRB) and factorial design (FD) statistical modes of analysis were used appropriately to discuss the results obtained. In order to choose any method of statistical analysis, the general chemistry underlying the assays, the types of molecules detected, the most important advantages and shortcomings of each method is vital to give a basis for the choice (Ronald *et al.*, 2005). Therefore, the stastistical tools used in interpreting the data are analysis of variance (ANOVA) technique. Means were compared by the Duncan's multiple range test, and significance was accepted at 5% level (p -value = 0.05).

CHAPTER 4

4.0 RESULTS

The results of percntage increase or decrese in proximate, mineral and anti-nutritional compositions of 'gari' and 'fufu' inoculated separately by *S. cerevisae* and *L. bulgaricus* are presented as shown in the following Figures.

4.1 The Results of Percentage Increase or Decrease of Proximate compositions

The result of percentage increase of crude protein contents of the microbial treated 'fufu' and 'gari obtained from Kontagora town is shown in Figure 4.1. The percentage increase in crude protein was highest in the *S. cerevisea*-inoculated 'fufu' made from L30572 and least value of percentage increase was in 'gari' prepared from 'Karimugi through *L. bulgaricus* fermentation (10.34%).

Figure 4.2 presents the crude protein percentage increase in the cassava products of Bida samples. *L. bulgaricus*-treated 'fufu' from 'Kpace dzuru' variety showed the highest increase, being 95.45%.

Result of the crude protein of the Suleja-obtained cassava products are presented in Figure 4.3. The result showed that *S. cerevisae*-treated 'gari' of the improved variety (TMS92/0326) had the highest percentage increase in crude protein (82.5%)

Figure 4.4 represents the percentage decrease in crude fibre of microbial obtained 'fufu' and 'gari' products produced from Kontagora cassava samples. The percentage decrease was highest in *S. cerevisea*-fermented 'fufu' from 'Karimugi' variety (78.33%), and lowest in *L. bulgaricus*-inoculated 'gari' produced from the same variety (10.34

Figure 4.5 shows the percentage crude fibre decrease for all fermented products of Bida samples site. The percentage decrease for the *L. bulgaricus* treated 'fufu' obtained from TME419 was 71.3% , *L. bulgaricus*- inoculated 'fufu' from 'Wahabi' had 38.7% and *S. cerevisae*-treated 'fufu' produced from L30572 achieved a 71.1% reduction.

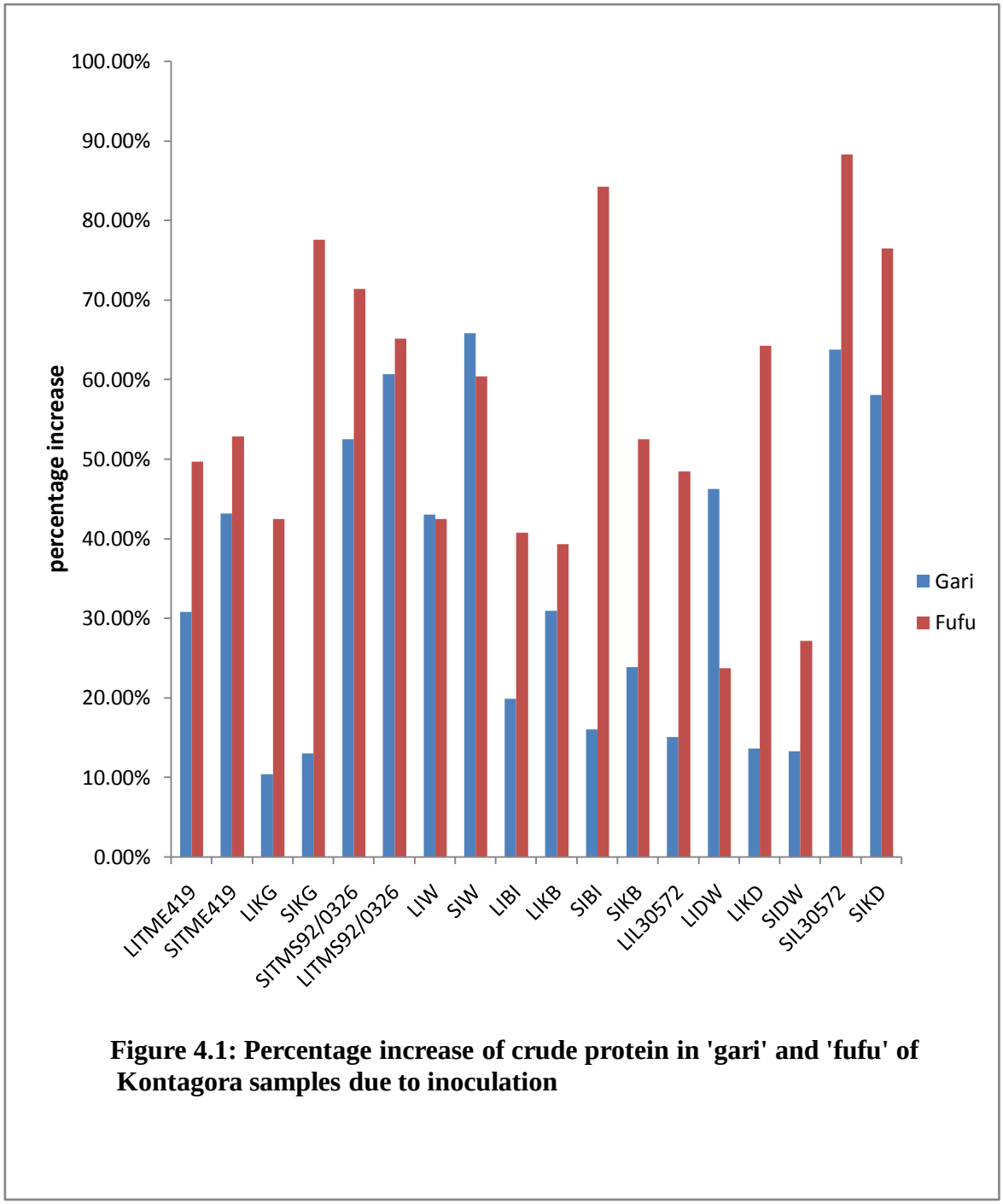


Figure 4.1: Percentage increase of crude protein in 'gari' and 'fufu' of Kontagora samples due to inoculation

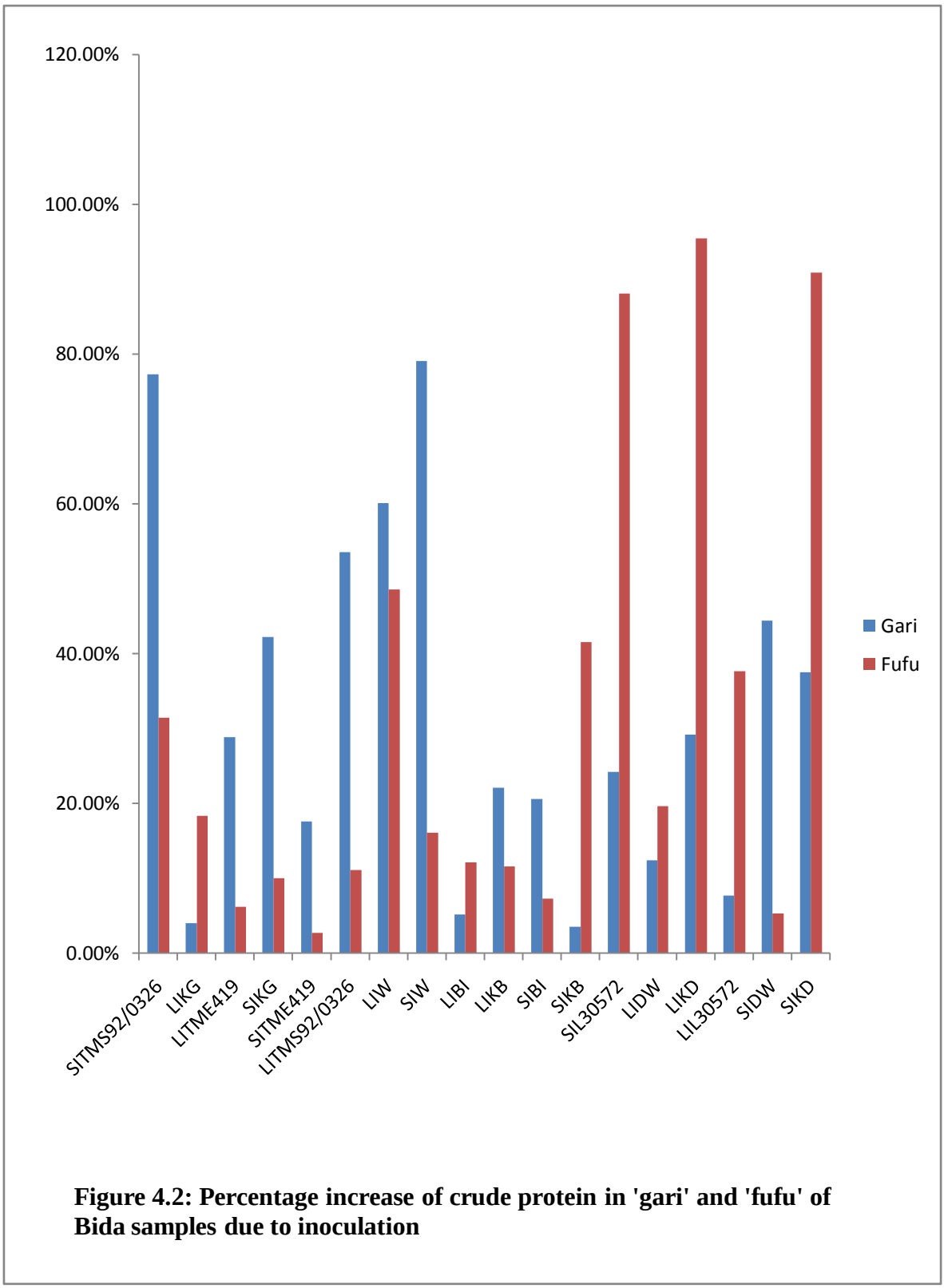


Figure 4.2: Percentage increase of crude protein in 'gari' and 'fufu' of Bida samples due to inoculation

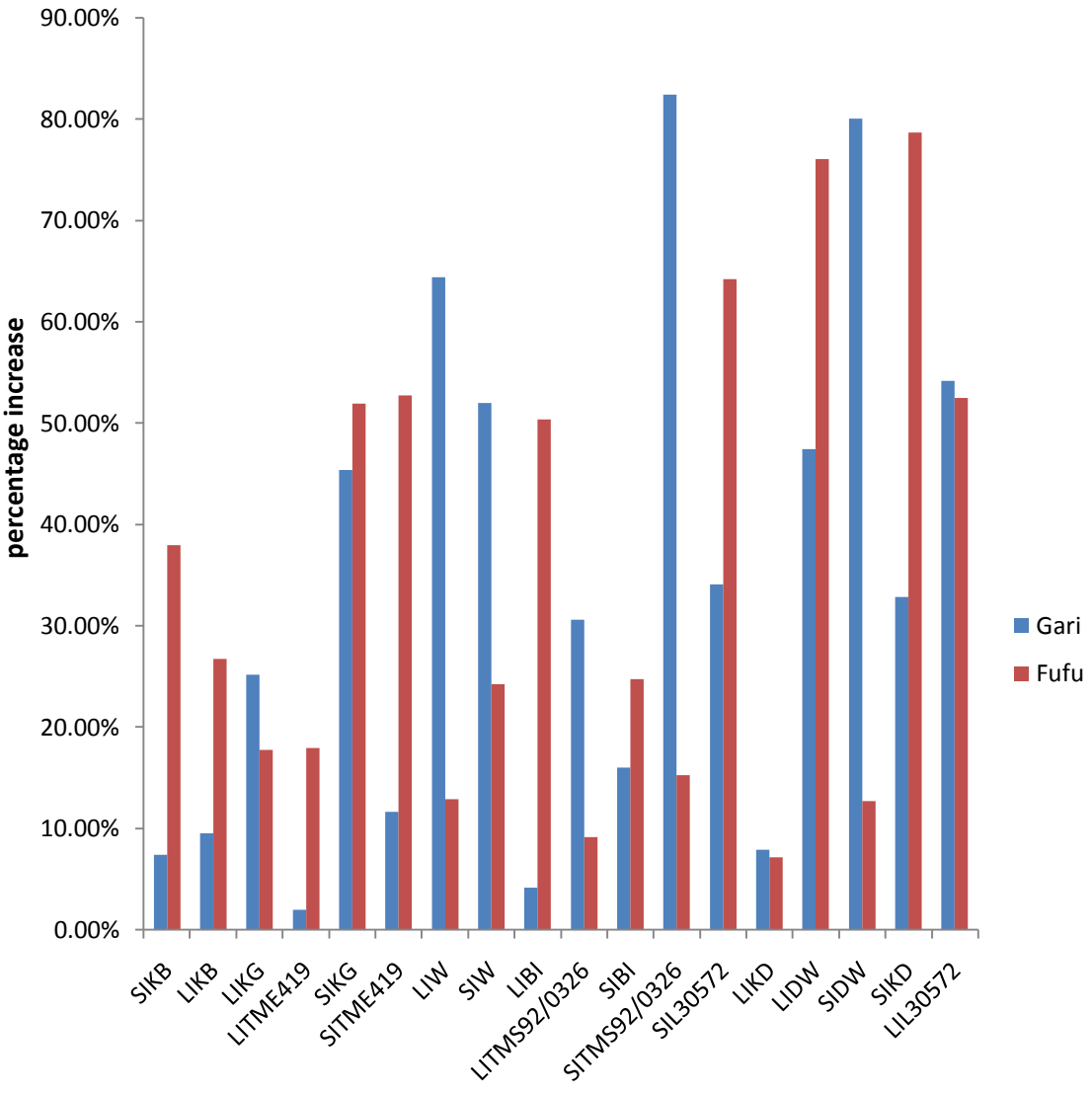


Figure 4.3: Percentage increase of crude protein increase in 'gari' and 'fufu of Suleja samples due to inoculation

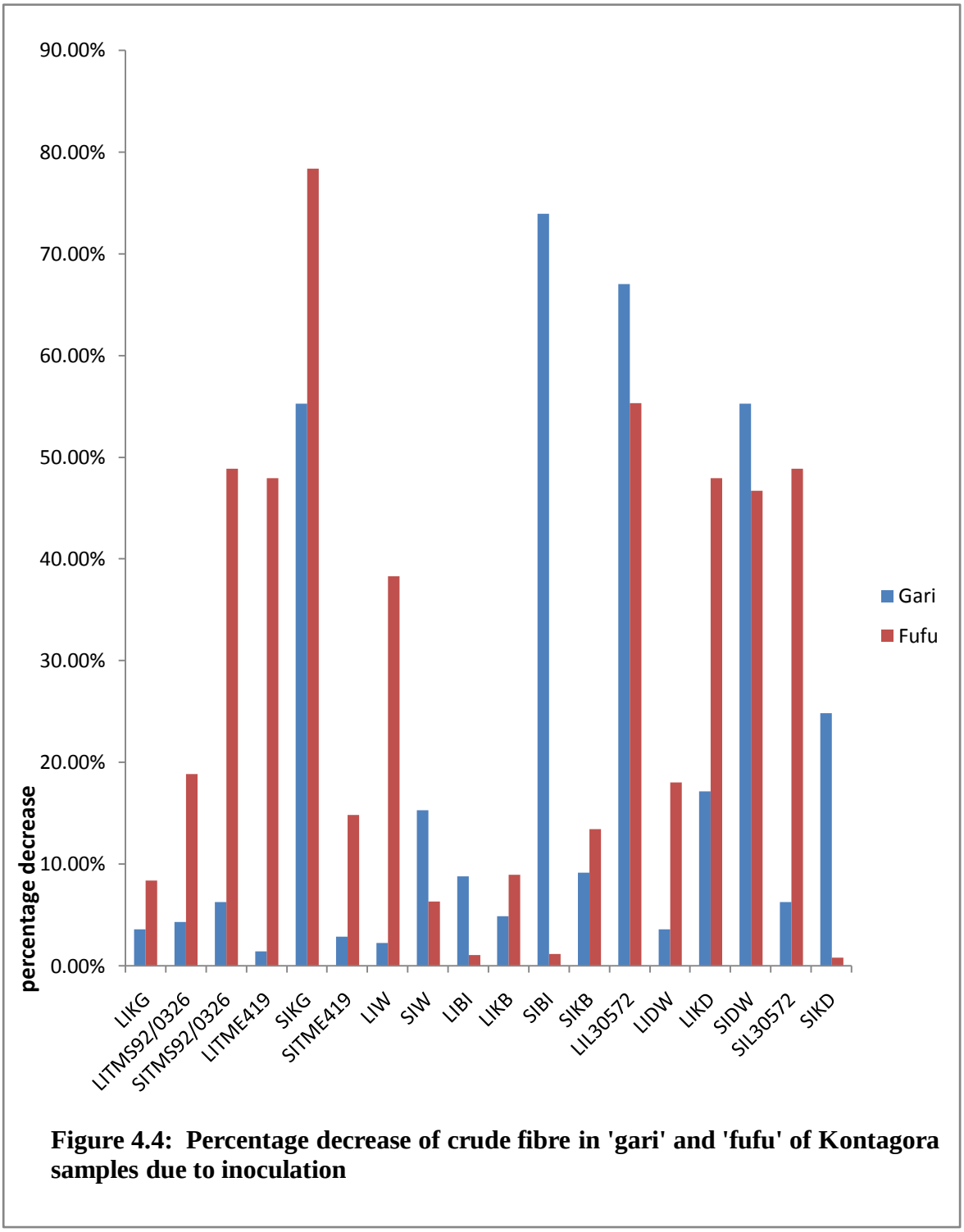


Figure 4.4: Percentage decrease of crude fibre in 'gari' and 'fufu' of Kontagora samples due to inoculation

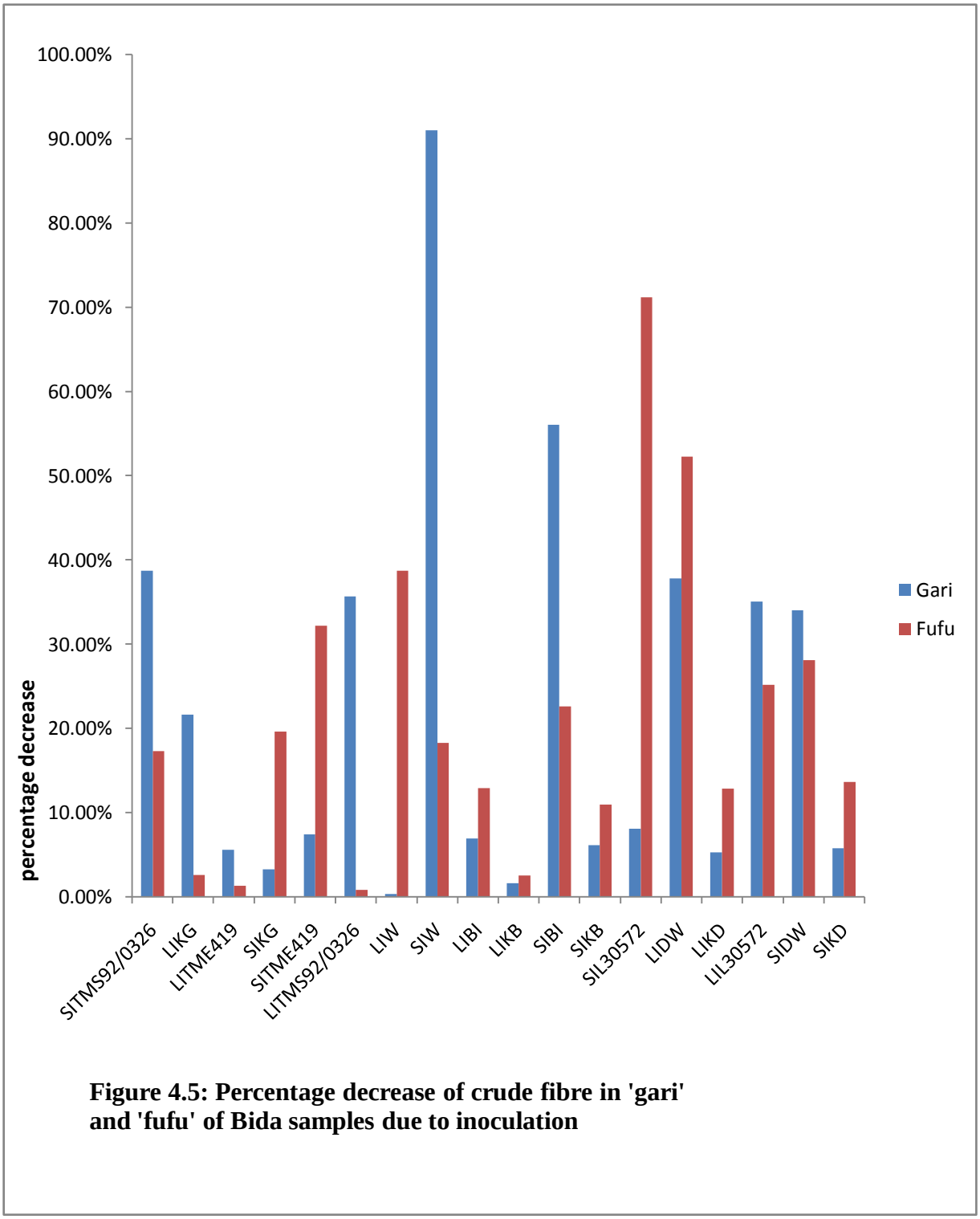


Figure 4.5: Percentage decrease of crude fibre in 'gari' and 'fufu' of Bida samples due to inoculation

4.6. The percentage decrease was highest in Baba Iya's 'fufu' (85.39%) fermented with *S. cerevisae,* TME419's and Dan Wari's 'fufu' (81.96% and 82.25% respectively), and Kpace Bokun's 'gari' (61.58%) inoculated with *L. bulgaricus,* while *S. cerevisae*-treated 'gari' from Baba Iya markedly recorded a 60.98% reduction in crude fibre.

Figure 4.7 presents the effects of the inoculants on the percentage increase of crude fat in the microbial inoculated 'fufu' and 'gari' products produced from Kontagora cassava samples. From the results, the highest percentage increase of 98.5% occurred in 'fufu' produced from 'Wahabi' inoculated with *L. bulgaricus.*

The result of crude fat percentage increase in the microbial produced 'fufu' and 'gari' products of Bida samples is shown in Figure 4.8. The percentage increase in the products indicated that there was a high significant elevation in crude fat for the 'gari' inoculated with *S. cerevisae* from 'Baba Iya' (75.87%), 'fufu' fermented with *L. bulgaricus* obtained from Baba Iya (84.9%) and 'fufu' fermented with *L. bulgaricus* from 'Kpace Bokun' (95%).

Figure 4.9 presents the result of crude fat obtained for 'fufu' and 'gari' products from Suleja province through microbial fermentation with *S. cerevisae* and *L. bulgaricus.* The *L. bulgaricus* treated 'fufu' from L30572 showed the highest percentage increase in crude fat (96.5%) and the lowest value was from TMS92/0326 *S. cerevisae*-treated 'gari' (0.21%).

The result of percentage decrease in carbohydrate contents of the Kontagora obtained cassava products is depicted in Figure 4.10. Highest percentage decrease in the carbohydrate was found in *S. cerevisae*-inoculated 'fufu' produced from 'Karimugi' and that from 'Kpace Bokun subjected to the same microbial treatment, with a decrease of 18.10% and 17.69% respectively.

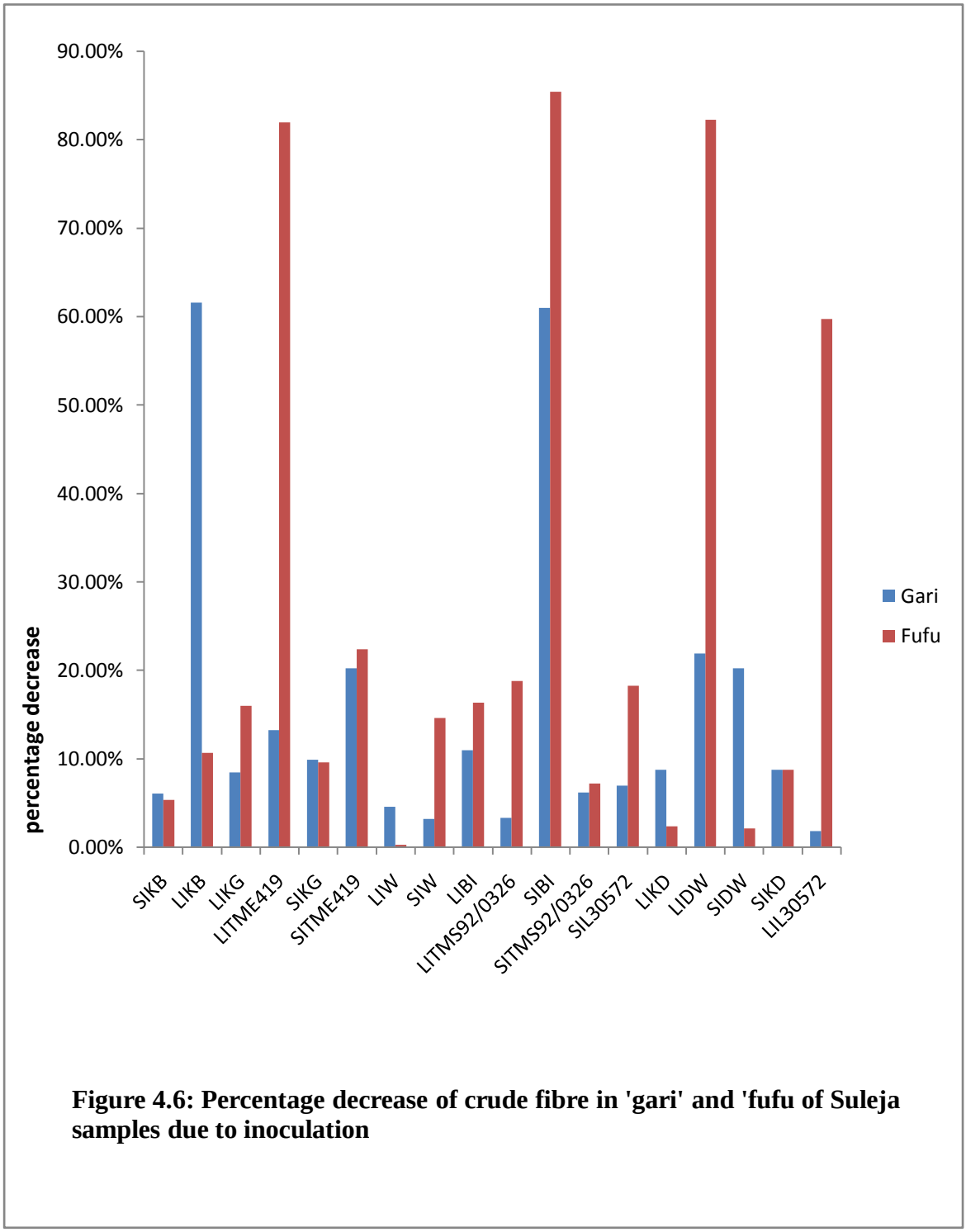


Figure 4.6: Percentage decrease of crude fibre in 'gari' and 'fufu of Suleja samples due to inoculation

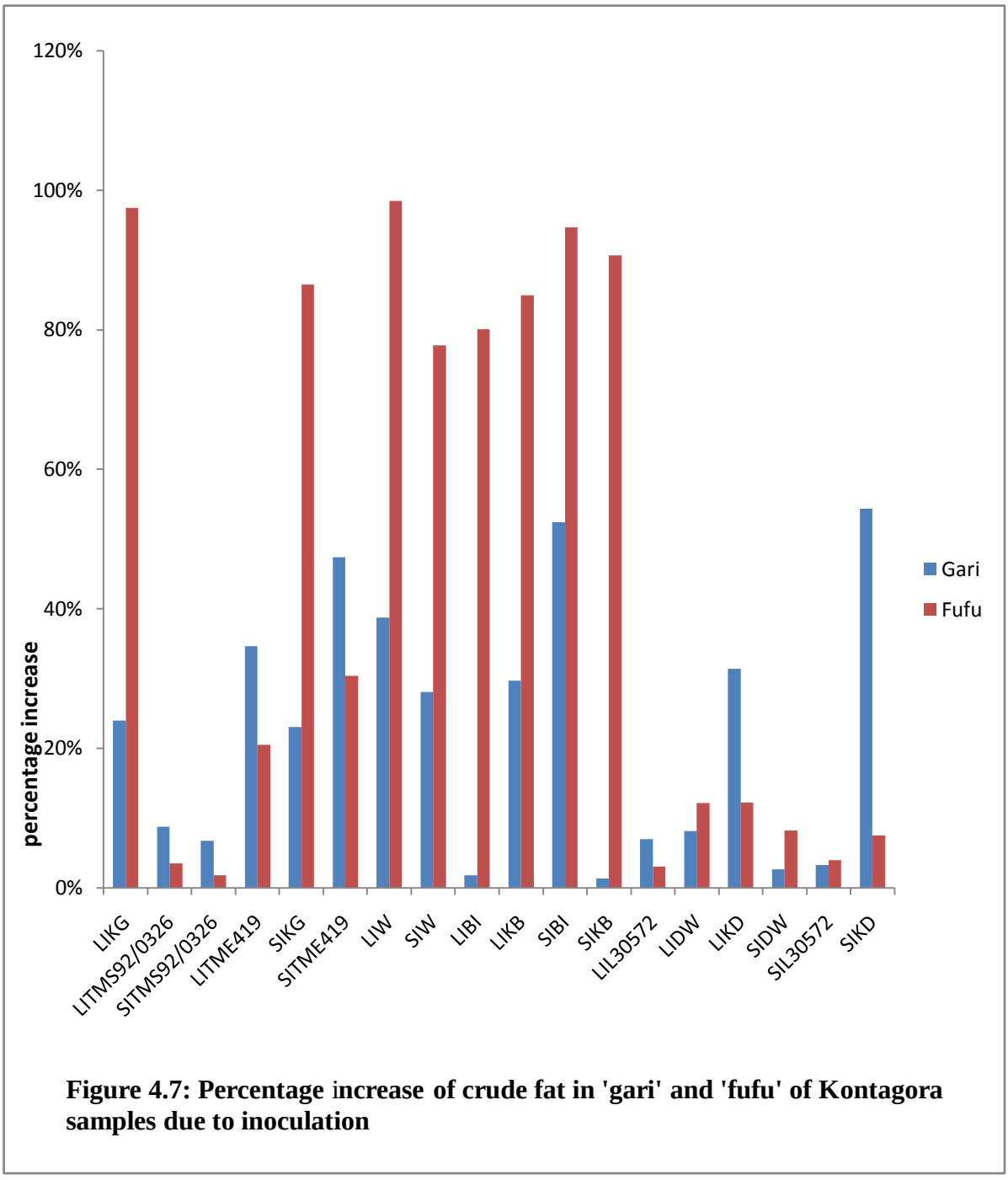


Figure 4.7: Percentage increase of crude fat in 'gari' and 'fufu' of Kontagora samples due to inoculation

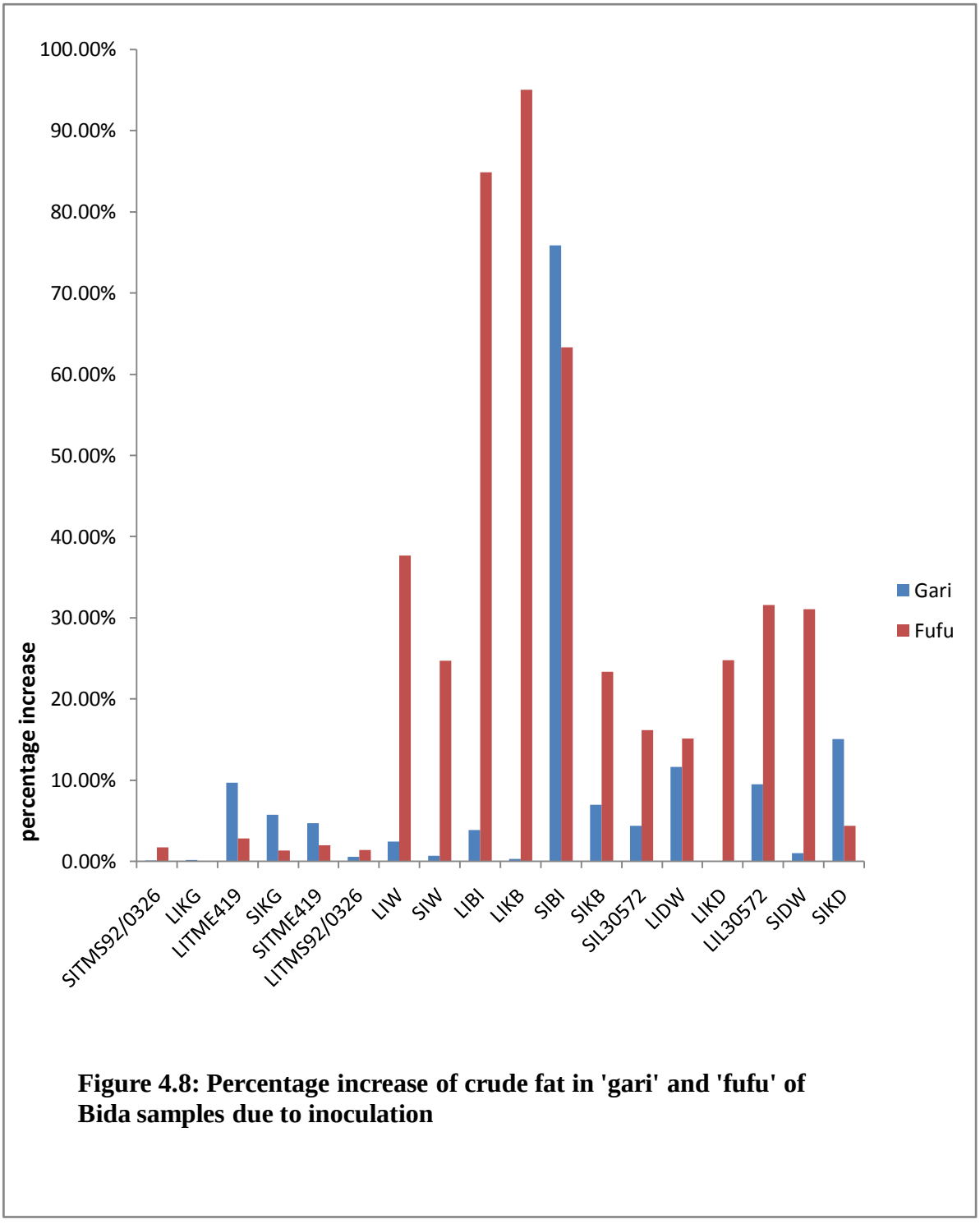


Figure 4.8: Percentage increase of crude fat in 'gari' and 'fufu' of Bida samples due to inoculation

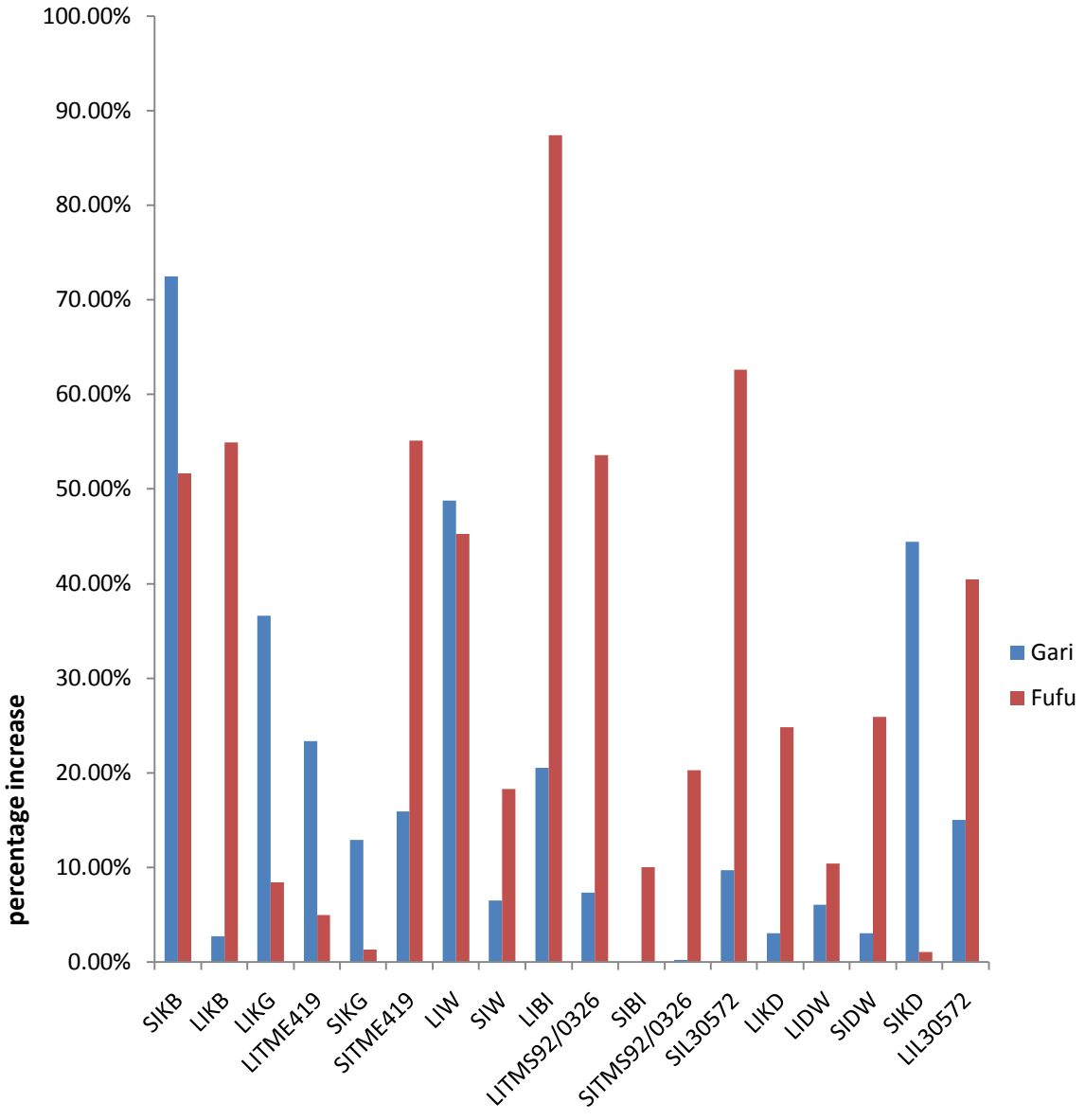


Figure 4.9: Percentage increase of crude fat in 'gari' and 'fufu' of Suleja samples due to inoculation

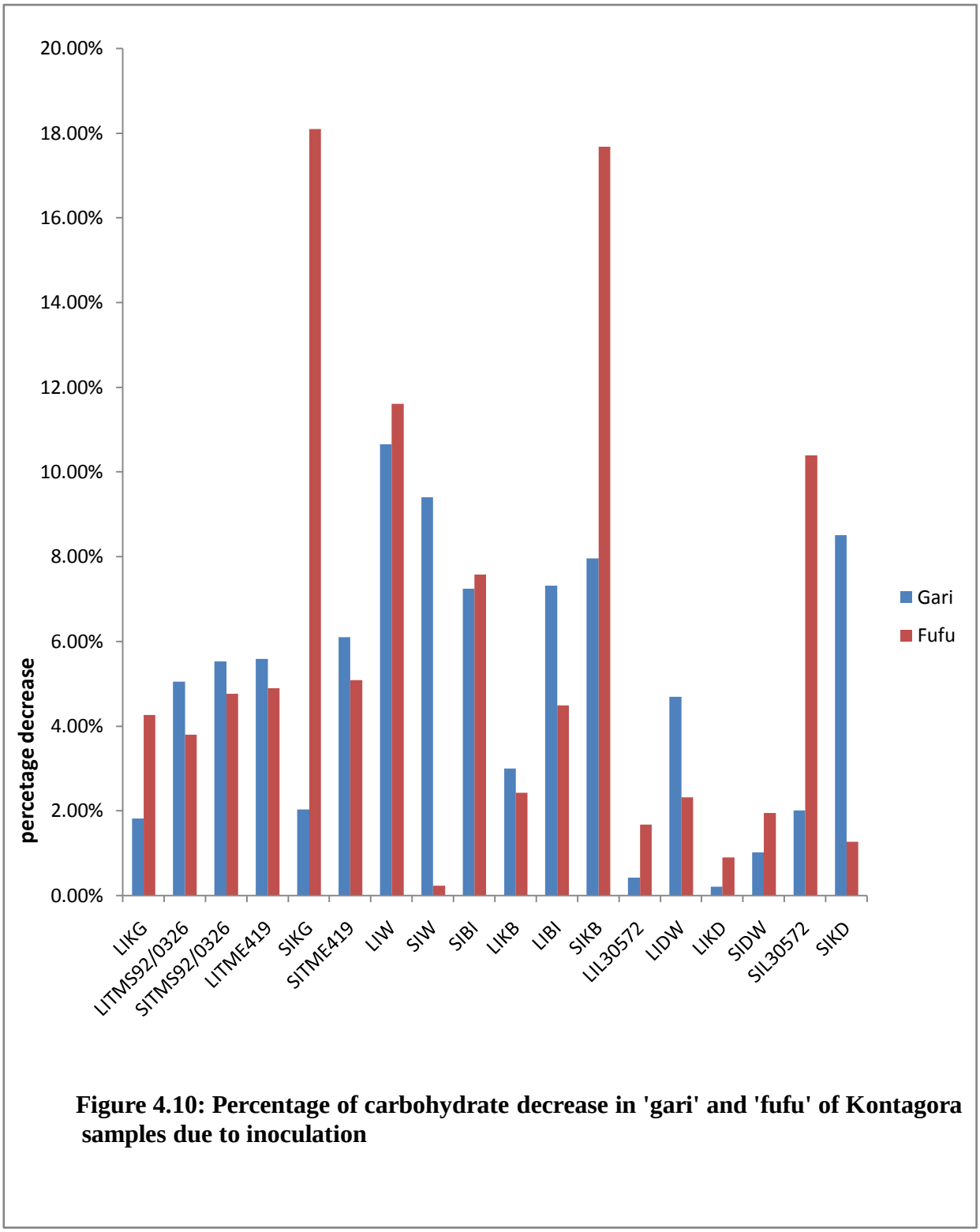


Figure 4.10: Percentage of carbohydrate decrease in 'gari' and 'fufu' of Kontagora samples due to inoculation

Figure 4.11 depicts the result obtained for percentage decrease in carbohydrate of 'fufu' and 'gari' products obtained from Bida town subjected to microbial treatment. The percentage decrease ranged from 9.7% in the *L. bulgaricus*-treated 'gari' from TME419 to 0.01% in the *L. bulgaricus* inoculated 'fufu' produced from 'Karimugi'.

The result of levels of percentage reduction in carbohydrate of 'fufu' and 'gari' products microbially fermented is presented in Figure 4.12. Although the percentage decrease was significantly low ($P > 0.05$) in the inoculated products, the decrease was almost equivalent in proportions in the 'gari' and 'fufu' products.

The result of percentage moisture composition of the various products obtained through microbial fermentation of Kontagora cassava samples is presented in Figure 4.13a and 4.13b. The result indicated that no clear trend was obtained for the moisture composition of the cassava products due inoculation after fermentation. Some products showed percentage increase (Figure 4.13a) while others showed percentage decrease (Figure 4.13a).

Figures 4.14a and 4.14b represent the results of percentage compositions of moisture in 'fufu' and 'gari' products of cassava samples of Bida. In the same vein, there existed no clear trend of relationship between the parameter and the microbial fermentation as some products showed increased percentage compositions (Figure 4.14a) while others had decreased percentage contents (Figure 4.14b).

Figures 4.15a and 4.15b show the results of moisture compositions of 'fufu'and 'gari' treated with the microbes of Suleja samples. From the result, there was a discerned relationship between the microbial fermentation and the moisture. Figure 4.15a presents the percentage increase while Figure 4.15b shows the percentage decrease of moisture.

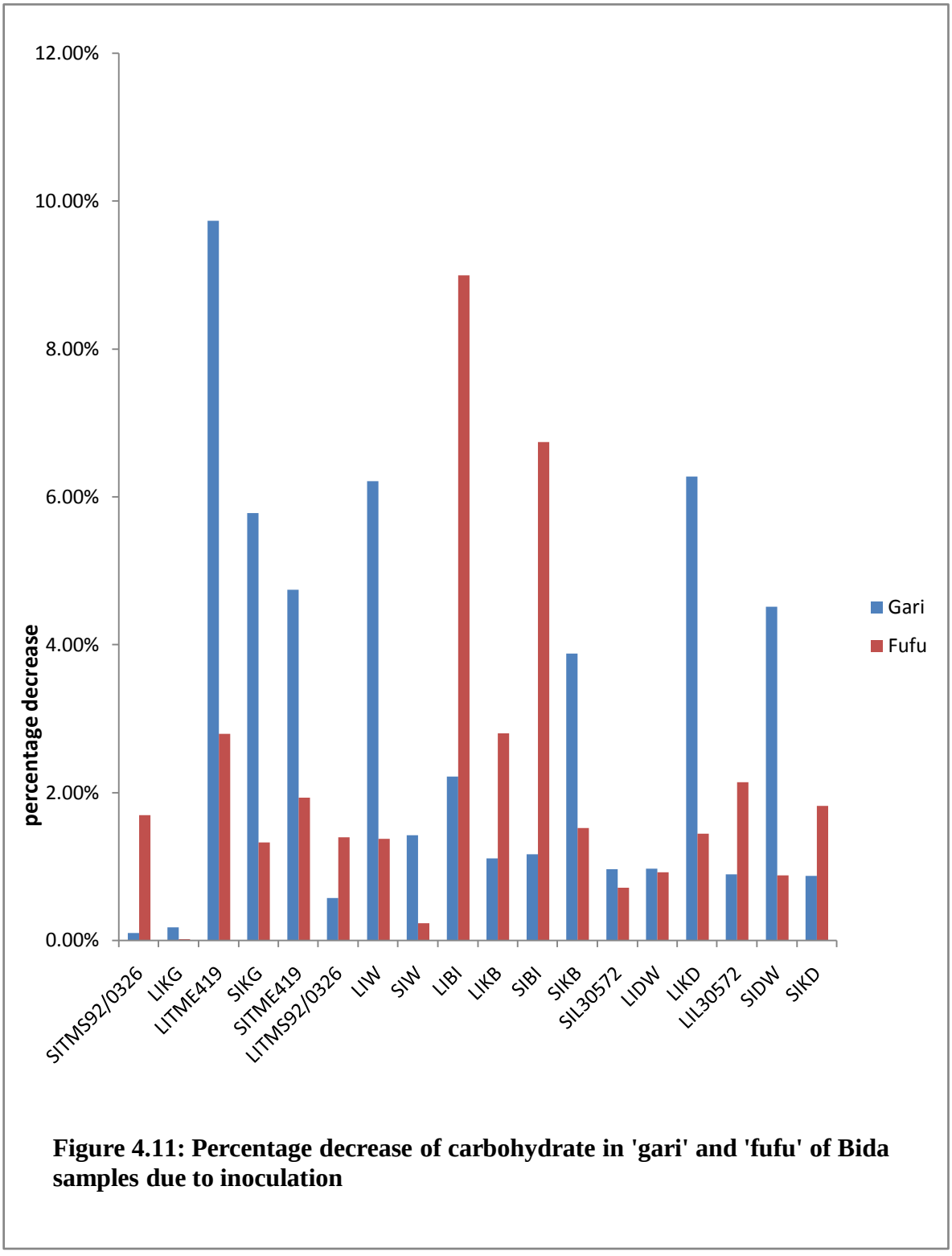


Figure 4.11: Percentage decrease of carbohydrate in 'gari' and 'fufu' of Bida samples due to inoculation

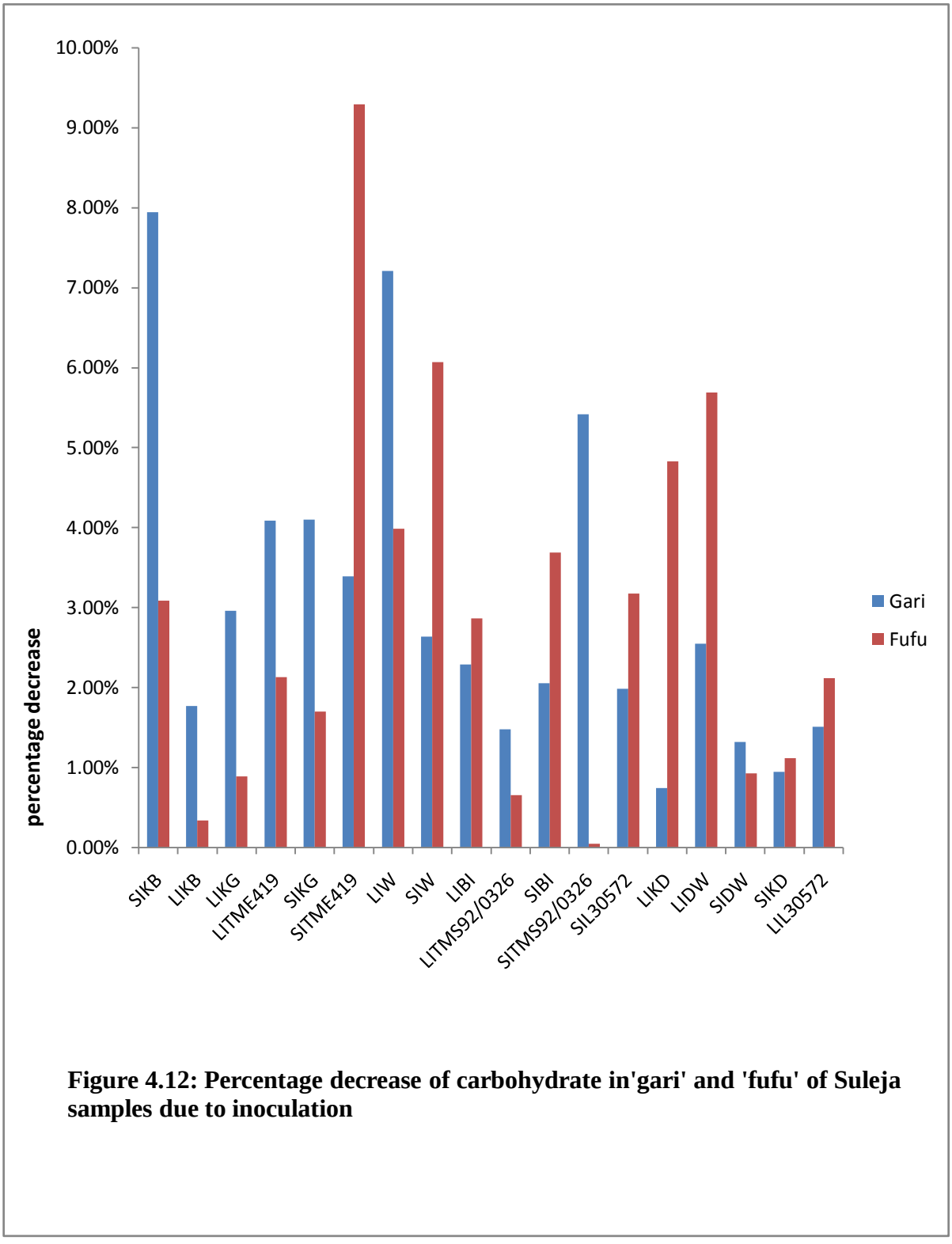


Figure 4.12: Percentage decrease of carbohydrate in'gari' and 'fufu' of Suleja samples due to inoculation

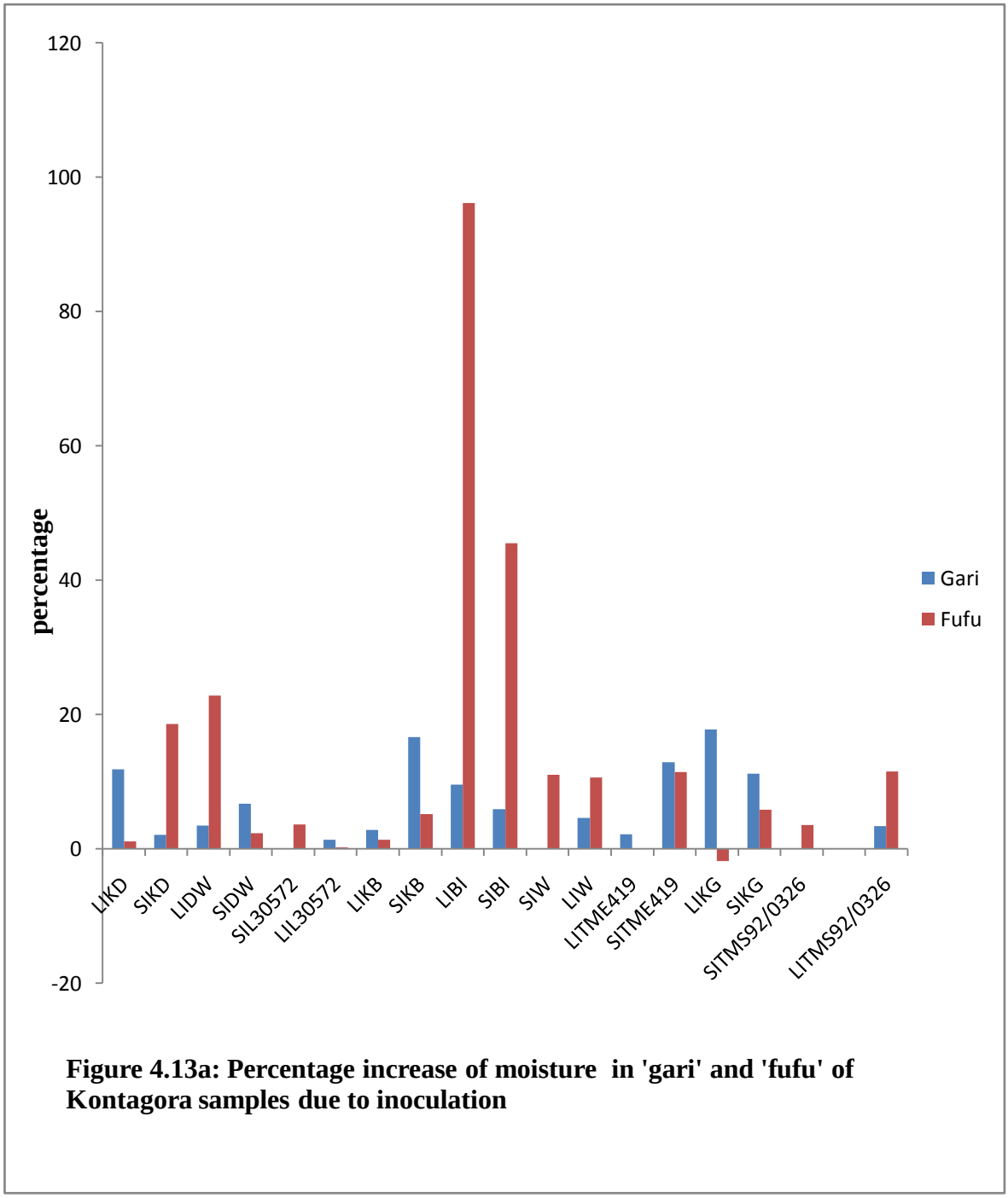


Figure 4.13a: Percentage increase of moisture in 'gari' and 'fufu' of Kontagora samples due to inoculation

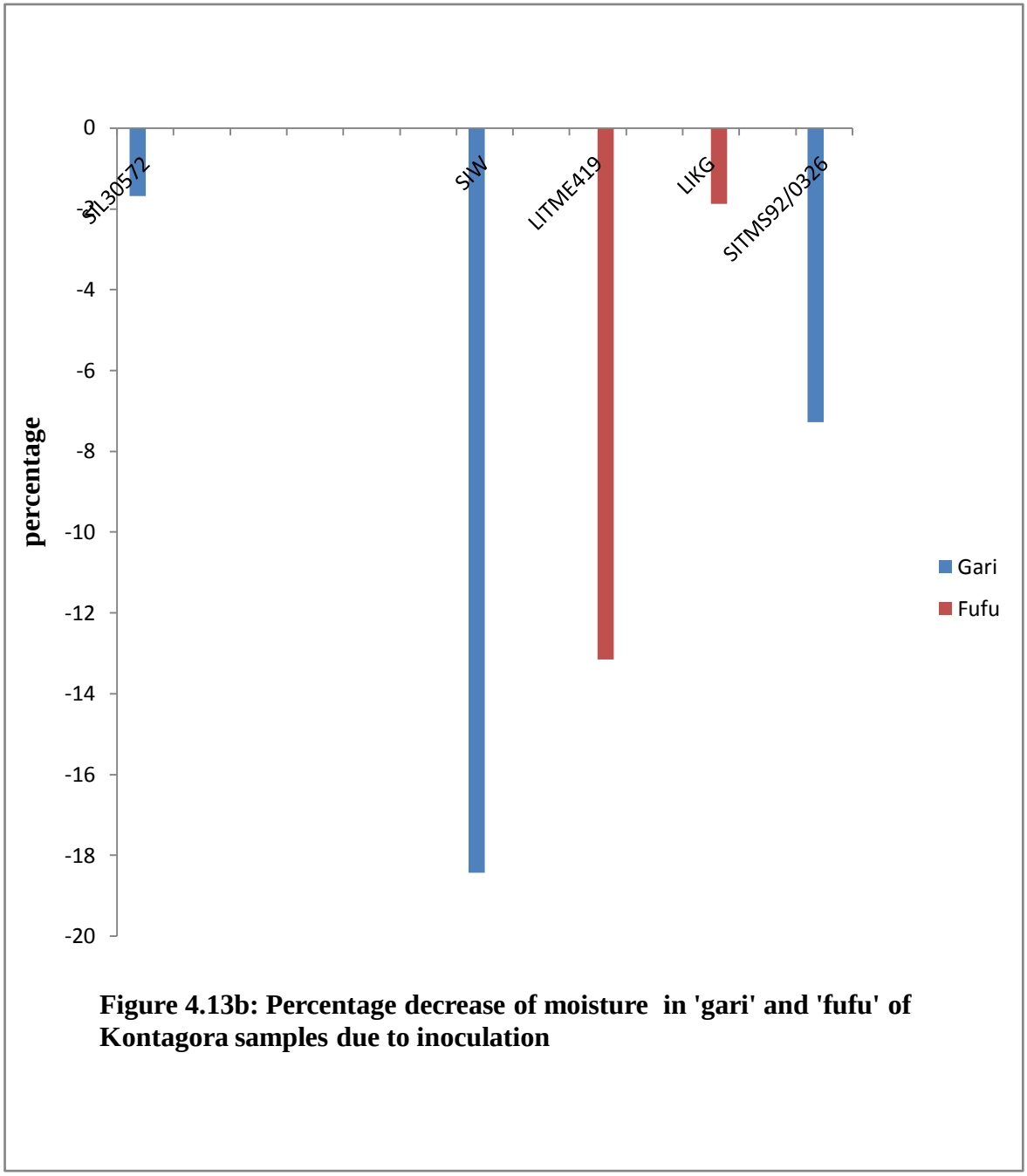


Figure 4.13b: Percentage decrease of moisture in 'gari' and 'fufu' of Kontagora samples due to inoculation

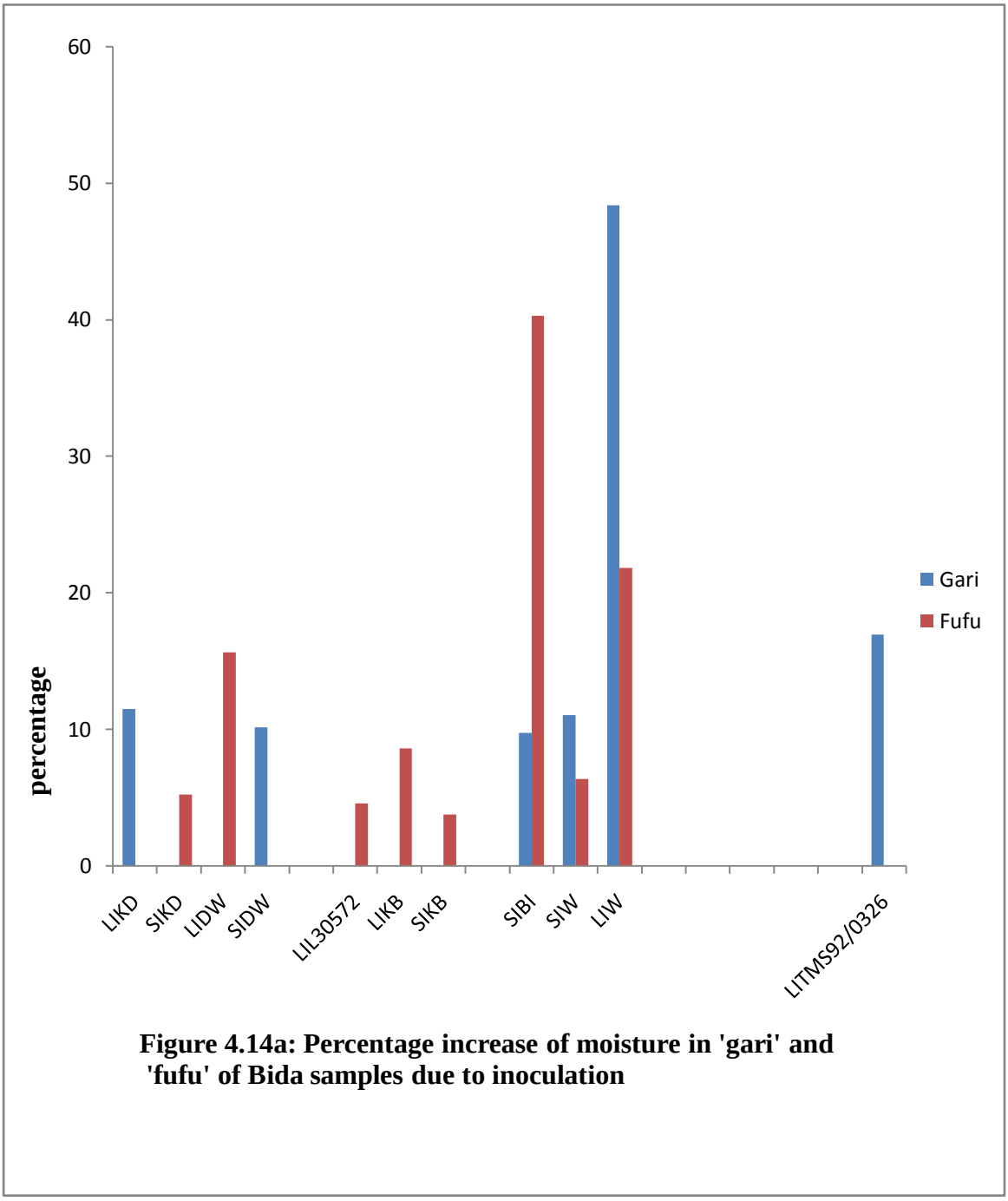


Figure 4.14a: Percentage increase of moisture in 'gari' and 'fufu' of Bida samples due to inoculation

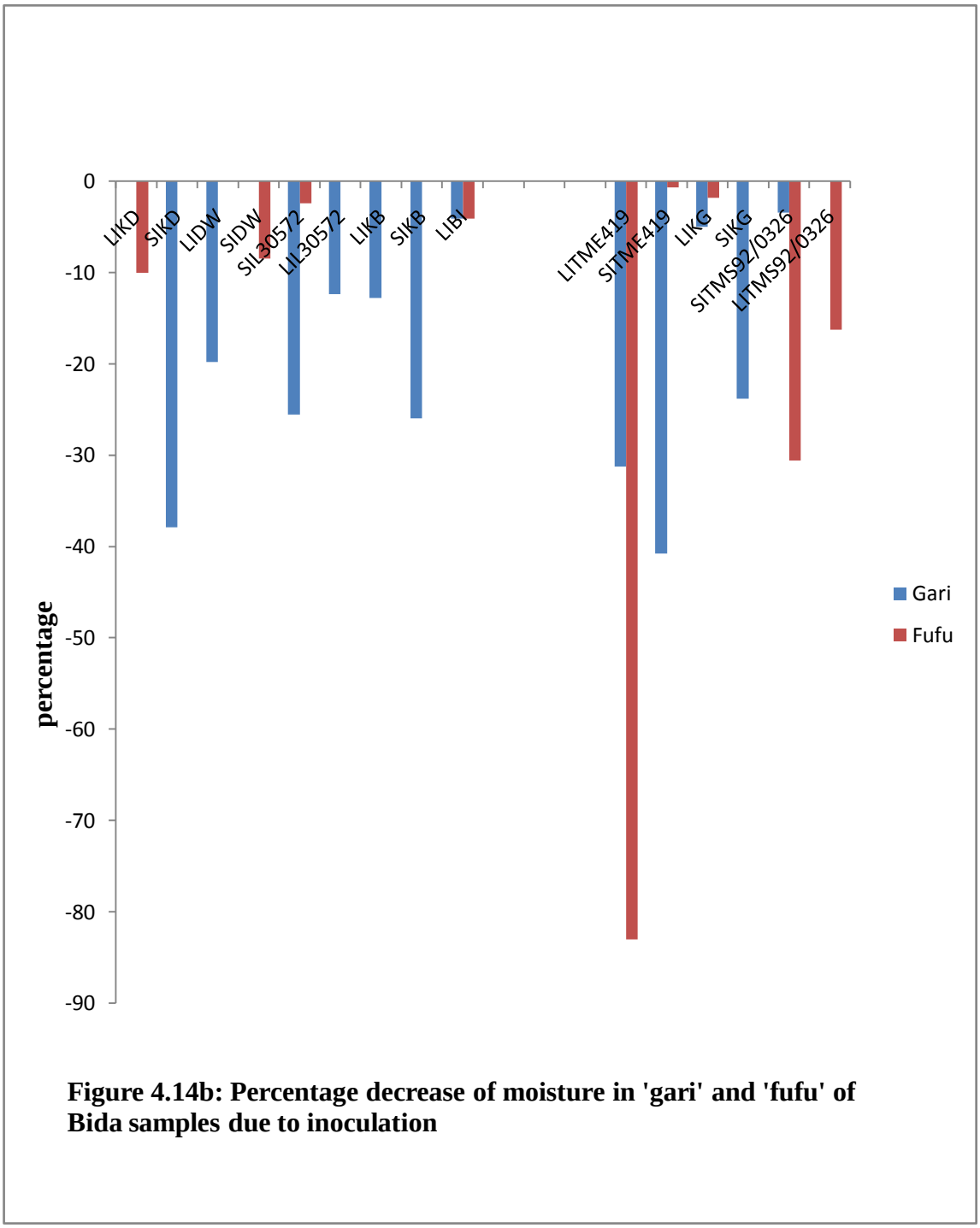


Figure 4.14b: Percentage decrease of moisture in 'gari' and 'fufu' of Bida samples due to inoculation

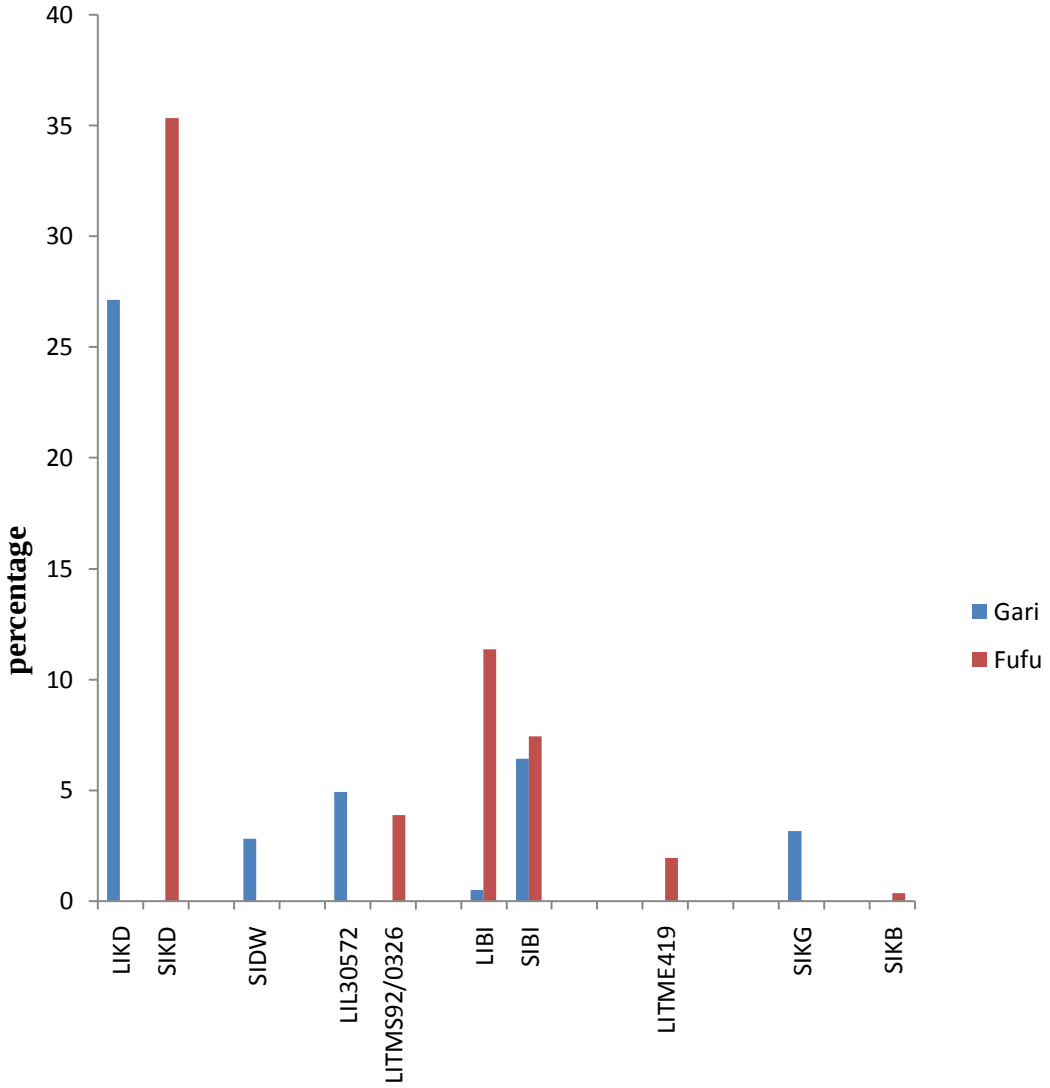


Figure 4.15a: Percentage increase of moisture in 'gari' and 'fufu' of Suleja samples due to inoculation

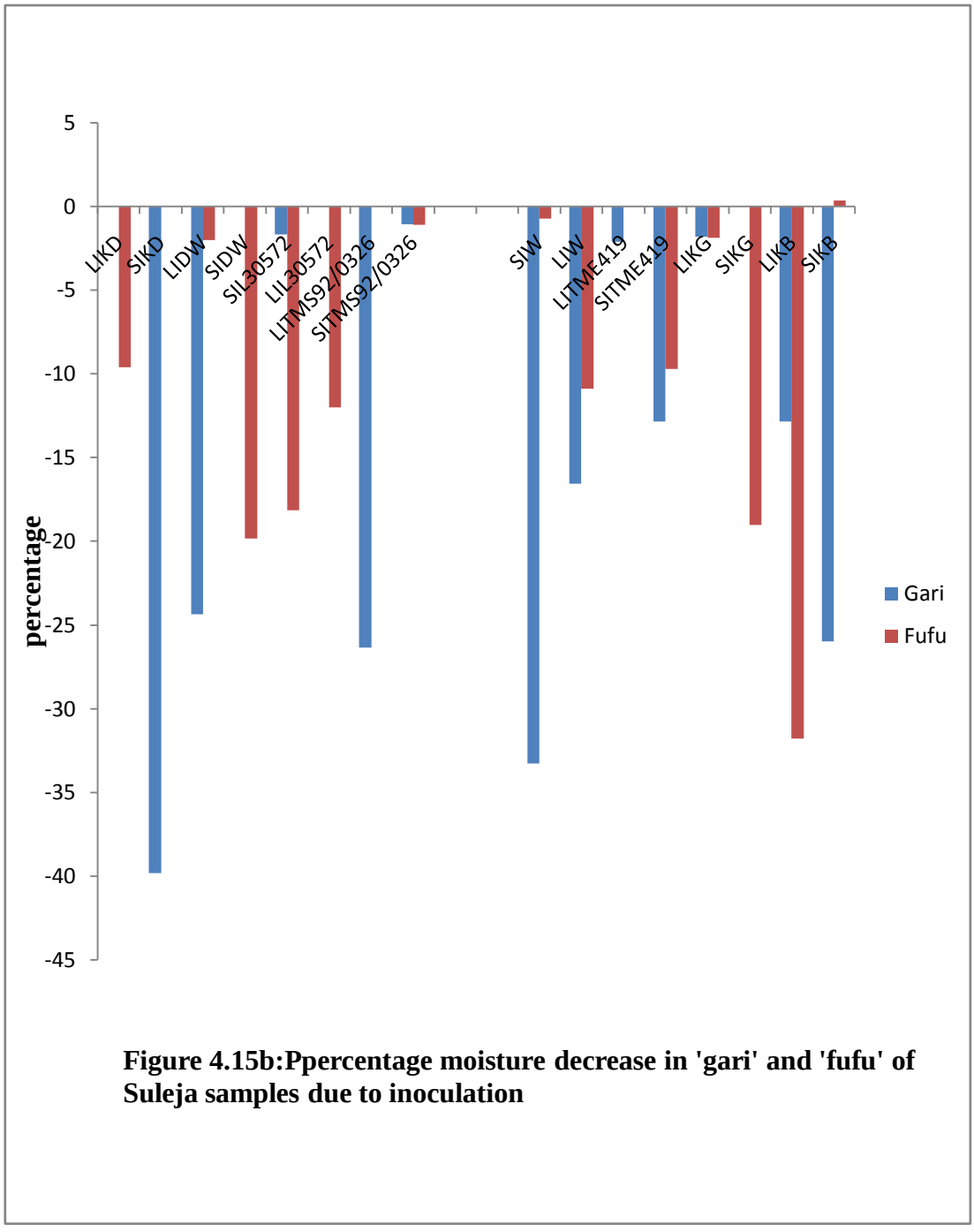


Figure 4.15b:Ppercentage moisture decrease in 'gari' and 'fufu' of Suleja samples due to inoculation

Figures 4.16a and 4.16b depict the percentage ash content in 'fufu' and 'gari products produced through microbial fermentation of Kontagora cassava samples. Like the moisture content, there was no clear trend among the values obtained, which indicated a poor relationship between ash content and fermentation. Figures 4.16a and 4.16b present increase and decrease in moisture compositions respectively.

The results of percentage compositions of ash in 'fufu' and gari products of cassava samples of Bida are represented in Figures 4.17a and 4.17b. There existed no clear trend of relationship between this parameter and the microbial fermentation. Figure 4.17a depicts increased ash contents while Figure 4.17b indicates decreased ash compositions

Figures 4.18a and 4.18b show the results of ash compositions of 'fufu'and 'gari' treated microbially of Suleja samples. The obvious trend of composition in Figures 4.18a and 4.18b was the occurrence of both percentage loss and increase in ash respectively.

Result of the total dry matter (TDM) content of 'fufu' and 'gari' produced from cassava products of Kontagora is presented in the Figures 4.19a 4.19b, indicating the percentage compositions. There was also a discernable relationship between TDM and fermentation like the ash and moisture compositions. Some percentage values increased (Figure 4.19a) while some decreased (Figures 4.19b). For example, *S. cerevisea*-treated 'gari' produced from 'Wahabi increased by 1.11% while *S. cerevisea*-treated 'fufu' obtained from the same variety got reduced by 0.70%.

Figures 4.20a and 4.20b represent the results of percentage compositions of total dry matter (TDM) in 'fufu' and gari products of cassava samples of Bida. In the same vein, there existed no clear trend of relationship between these parameters and the microbial fermentation. Some percentage values increased (Figure 4.20a) while some decreased (Figures 4.20b).

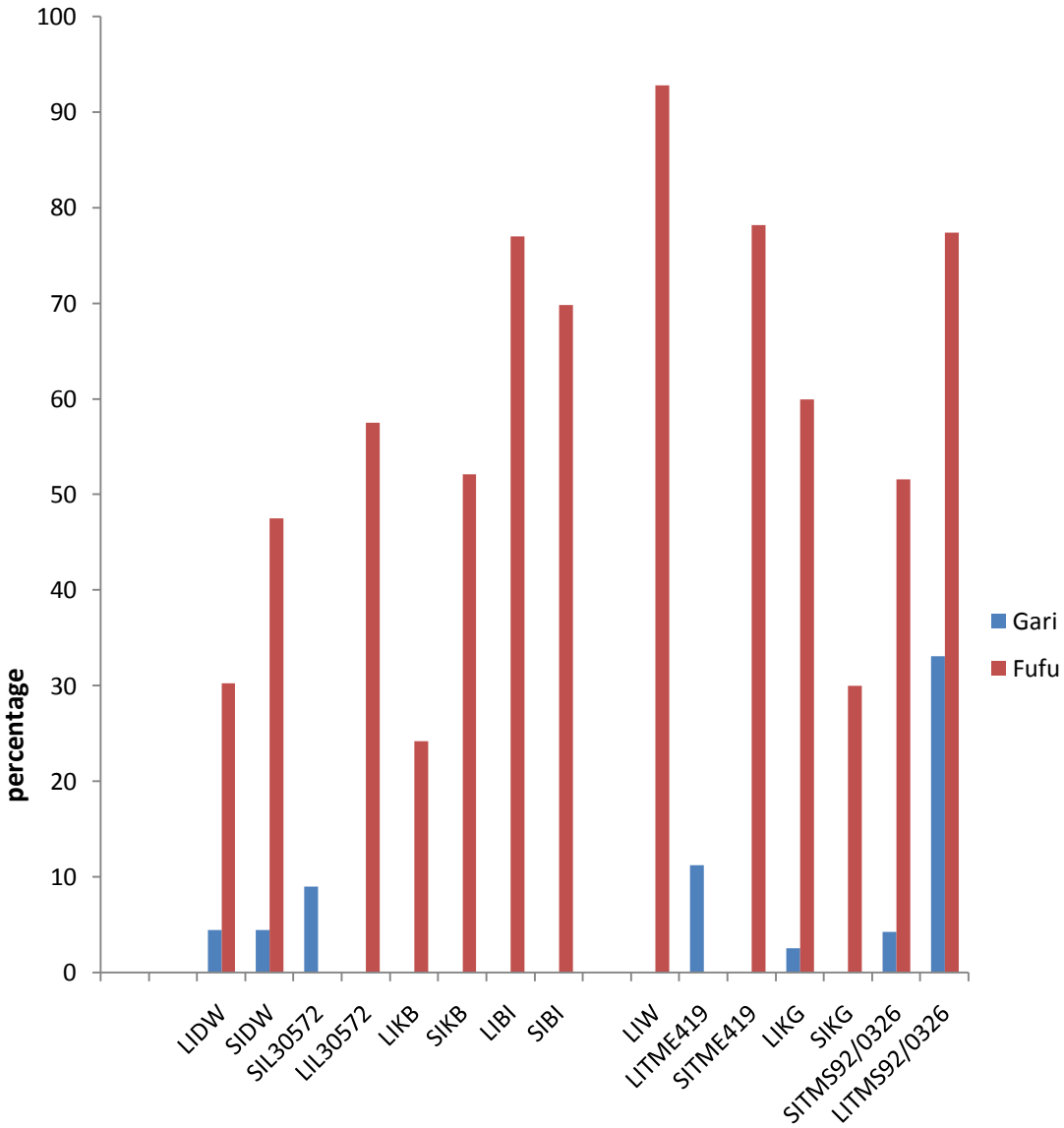


Figure 4.16a: Percentage increase of ash in 'gari' and 'fufu' of Kontagora samples due to inoculation

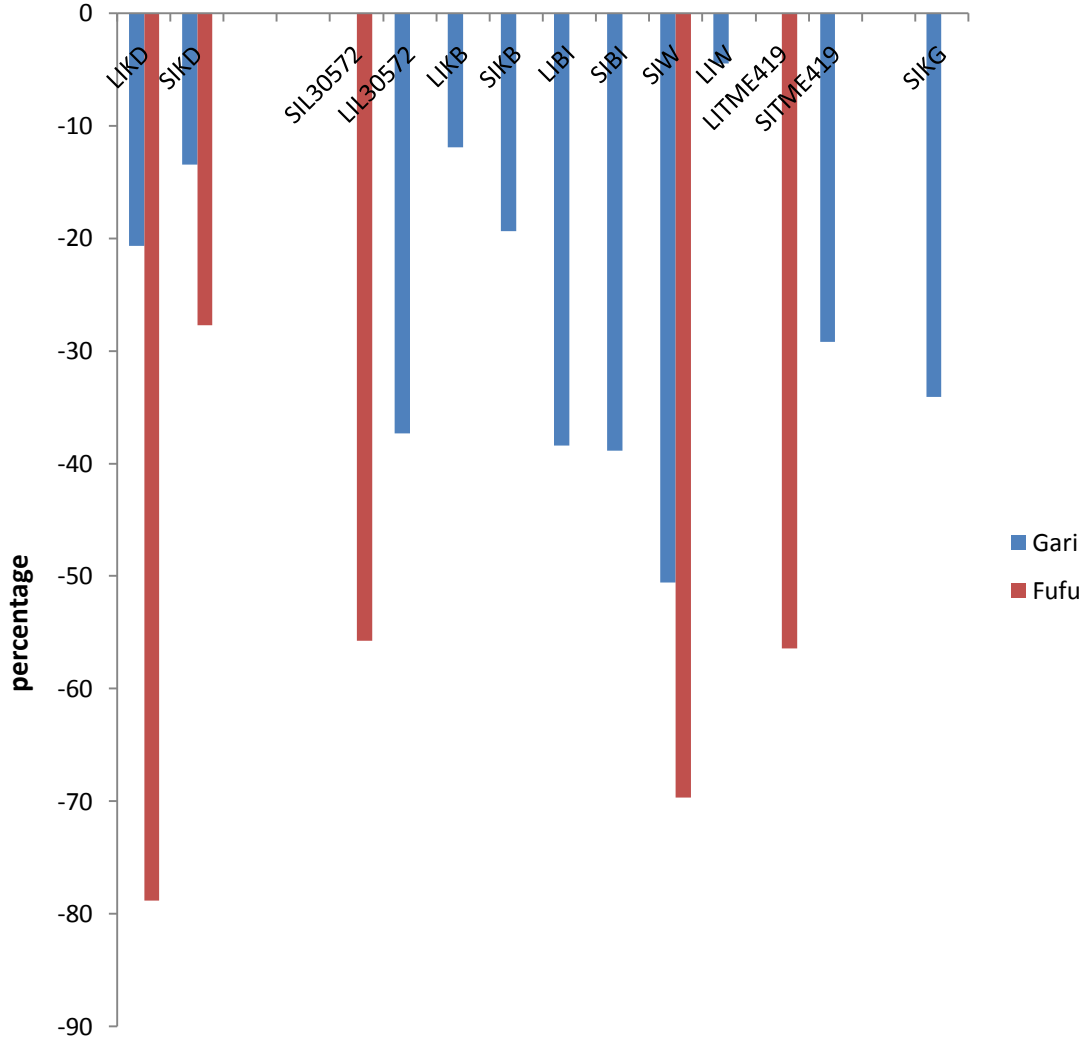


Figure 4.16b: Percentage decrease of ash in 'gari' and 'fufu' of Kontagora samples due to inoculation

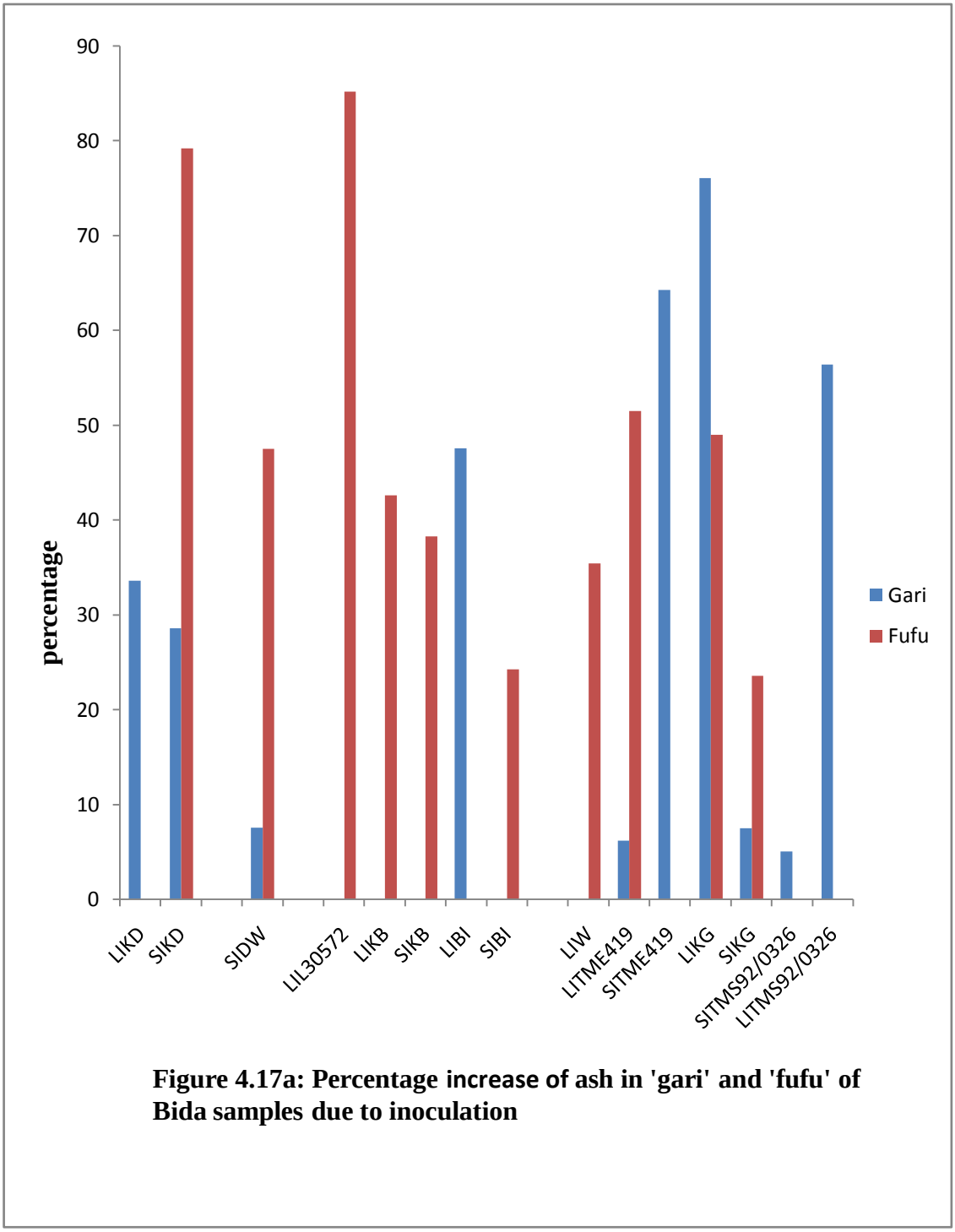


Figure 4.17a: Percentage increase of ash in 'gari' and 'fufu' of Bida samples due to inoculation

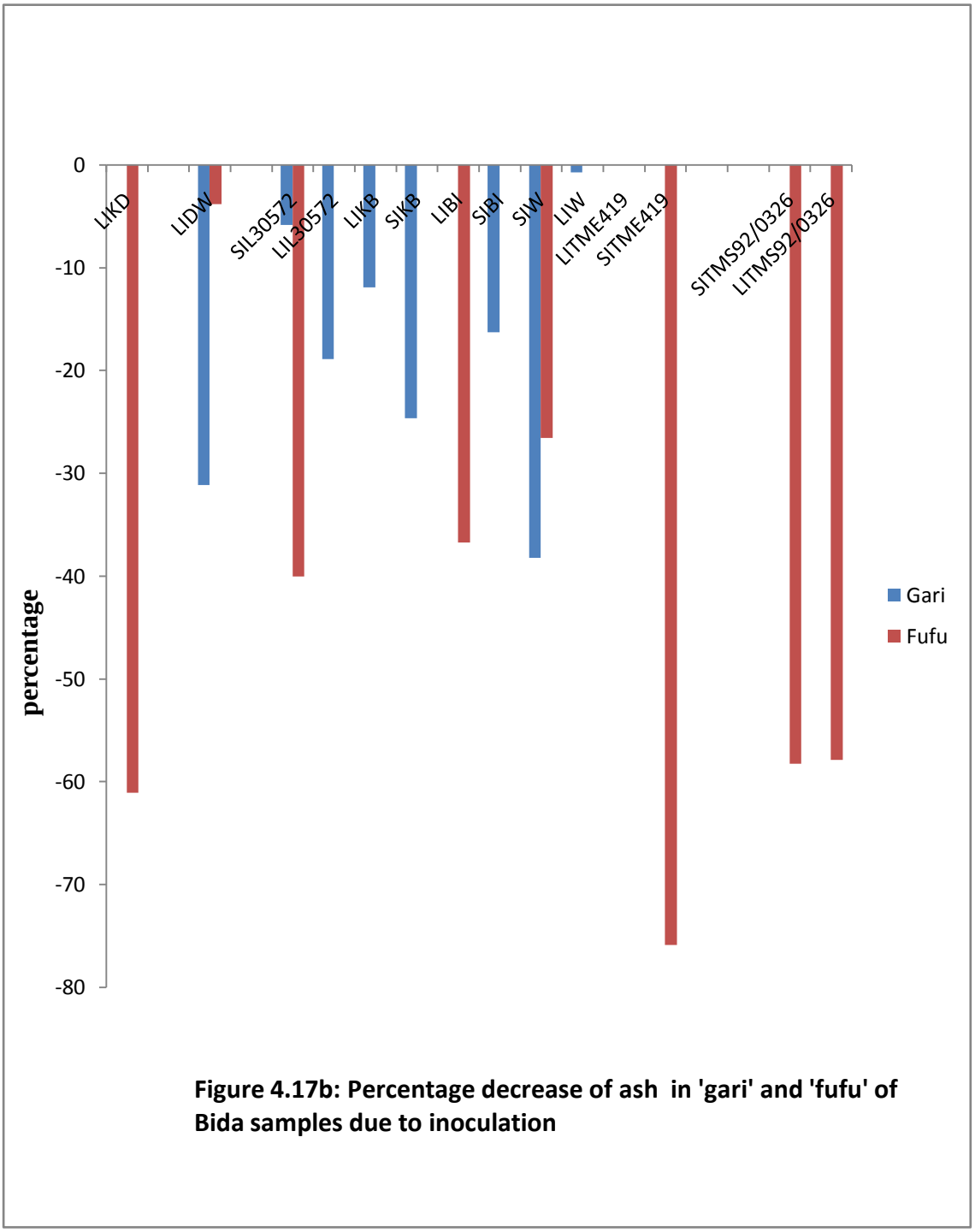


Figure 4.17b: Percentage decrease of ash in 'gari' and 'fufu' of Bida samples due to inoculation

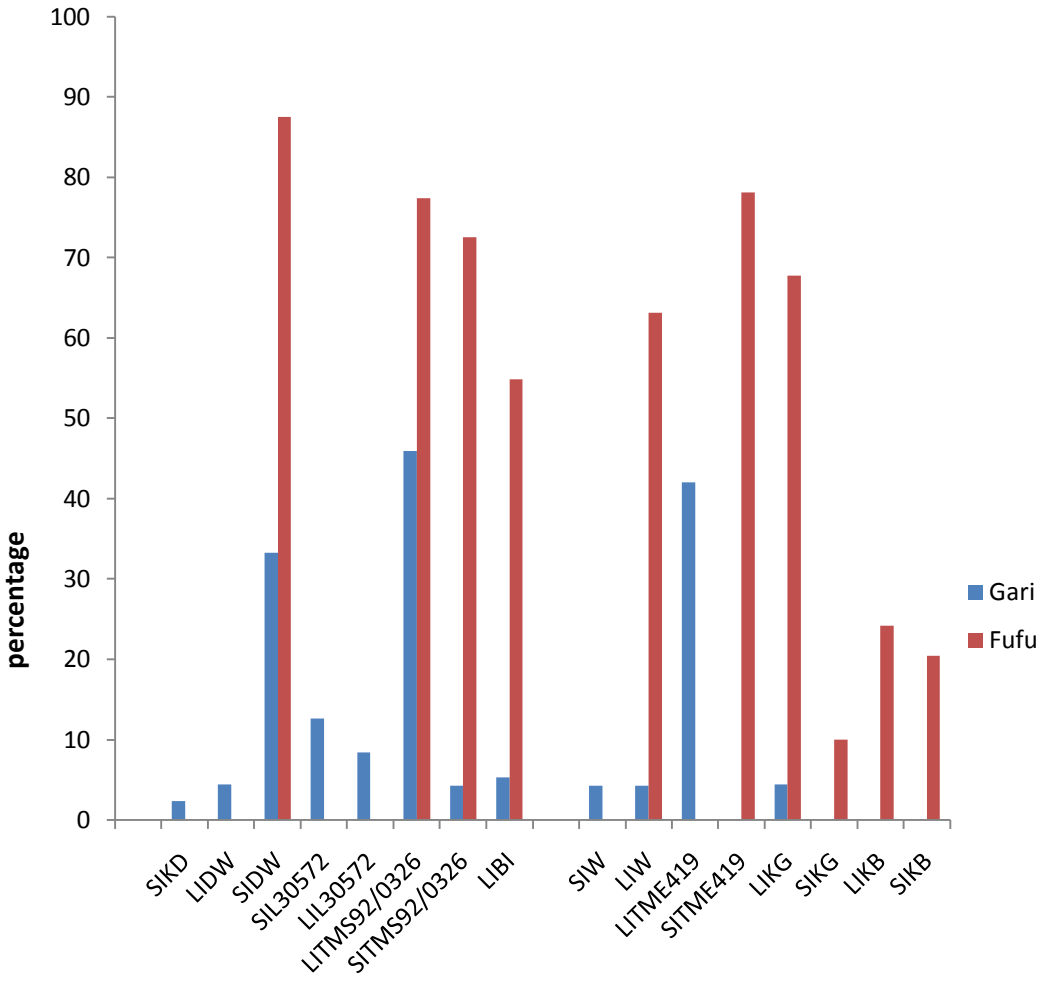


Figure 4.18a: Percentage increase of ash in 'gari' and 'fufu' of Suleja samples due to inoculation

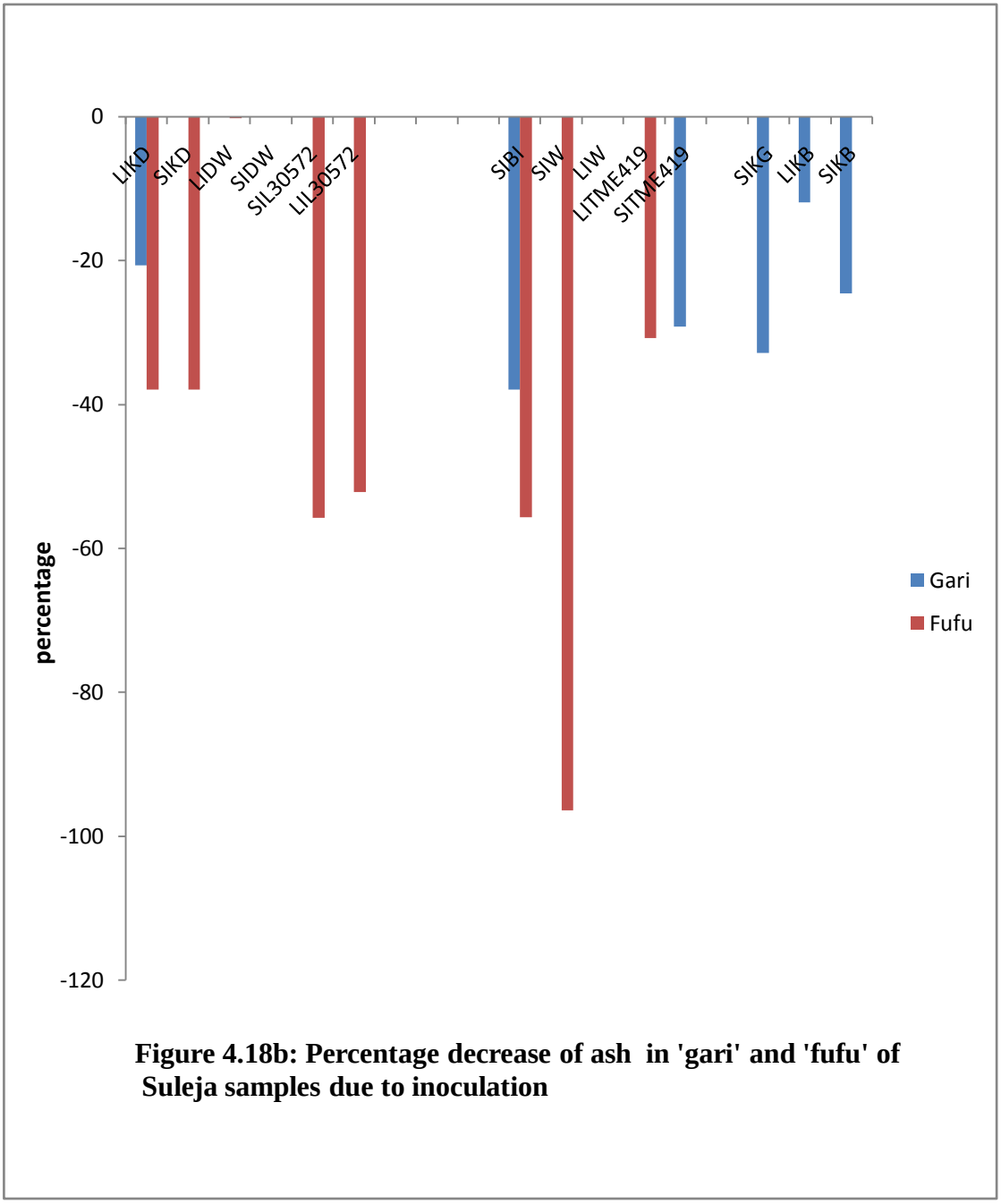


Figure 4.18b: Percentage decrease of ash in 'gari' and 'fufu' of Suleja samples due to inoculation

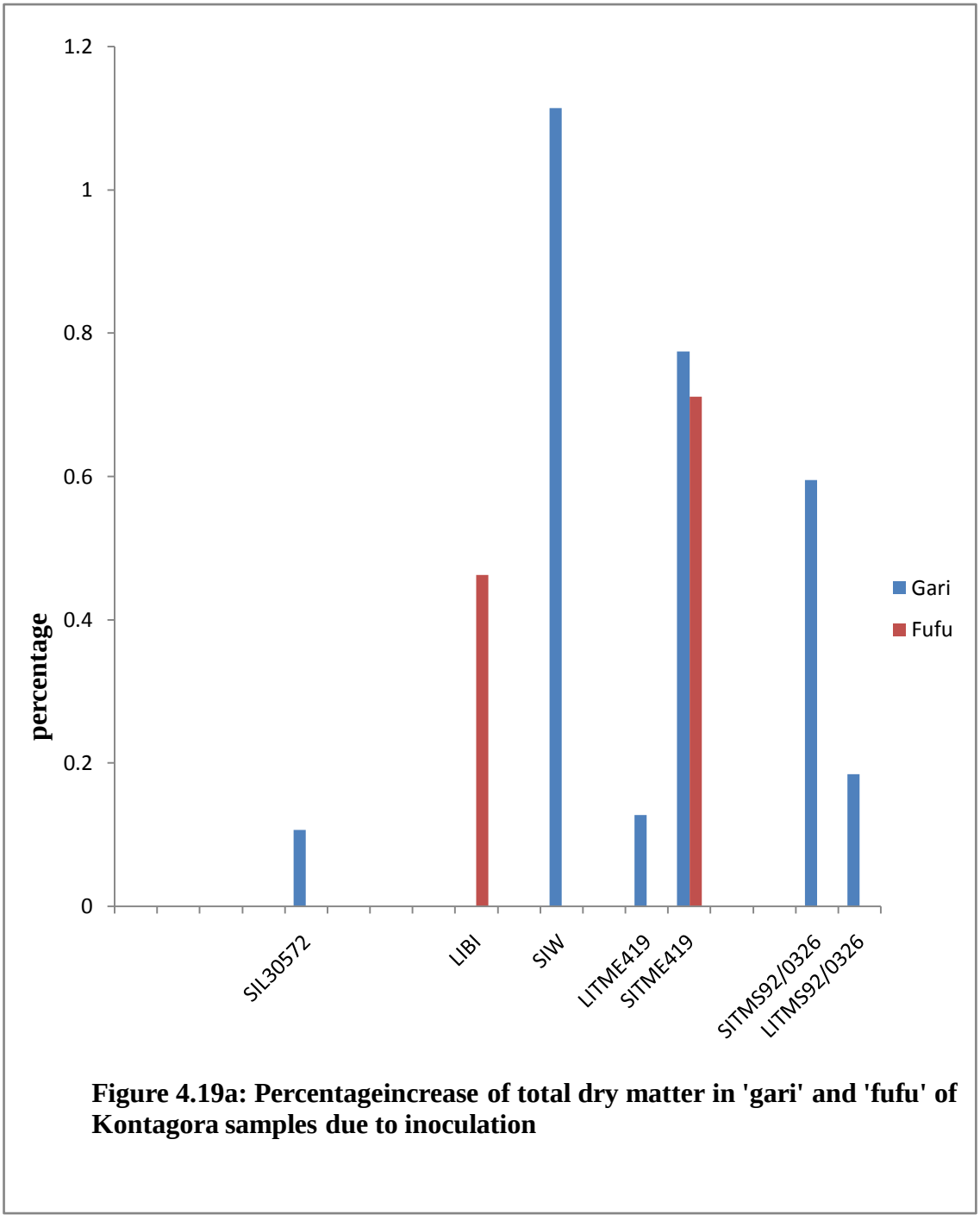


Figure 4.19a: Percentageincrease of total dry matter in 'gari' and 'fufu' of Kontagora samples due to inoculation

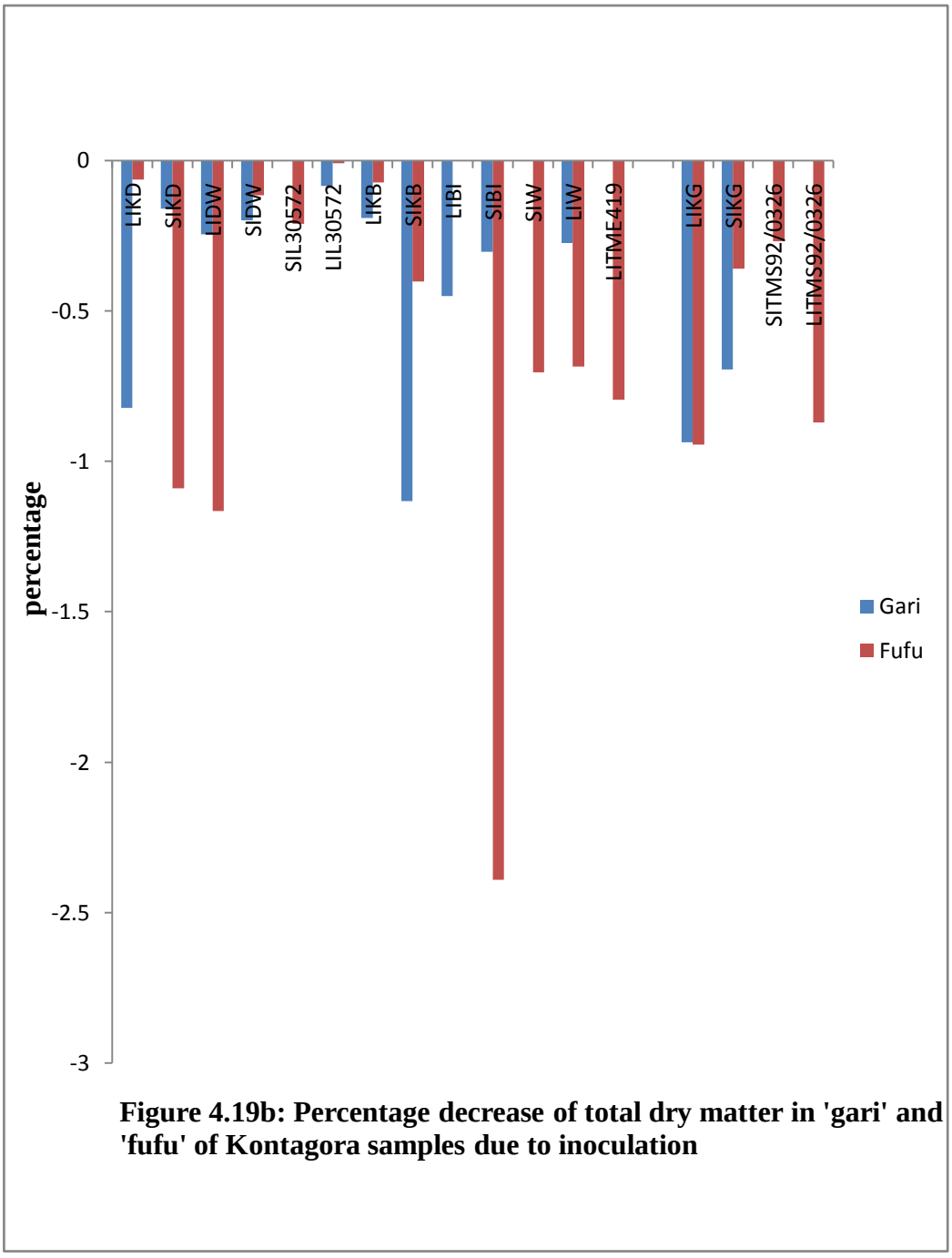


Figure 4.19b: Percentage decrease of total dry matter in 'gari' and 'fufu' of Kontagora samples due to inoculation

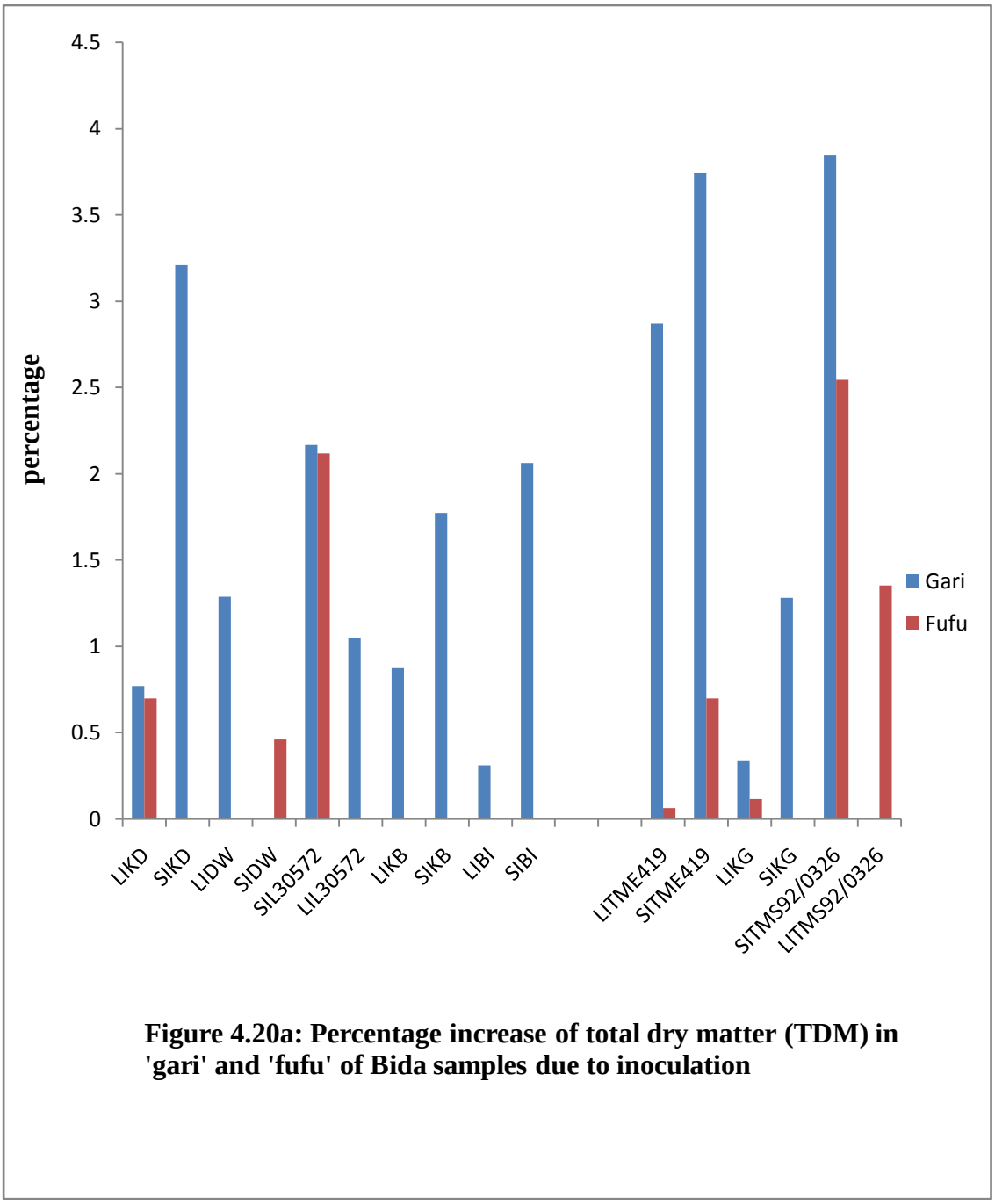


Figure 4.20a: Percentage increase of total dry matter (TDM) in 'gari' and 'fufu' of Bida samples due to inoculation

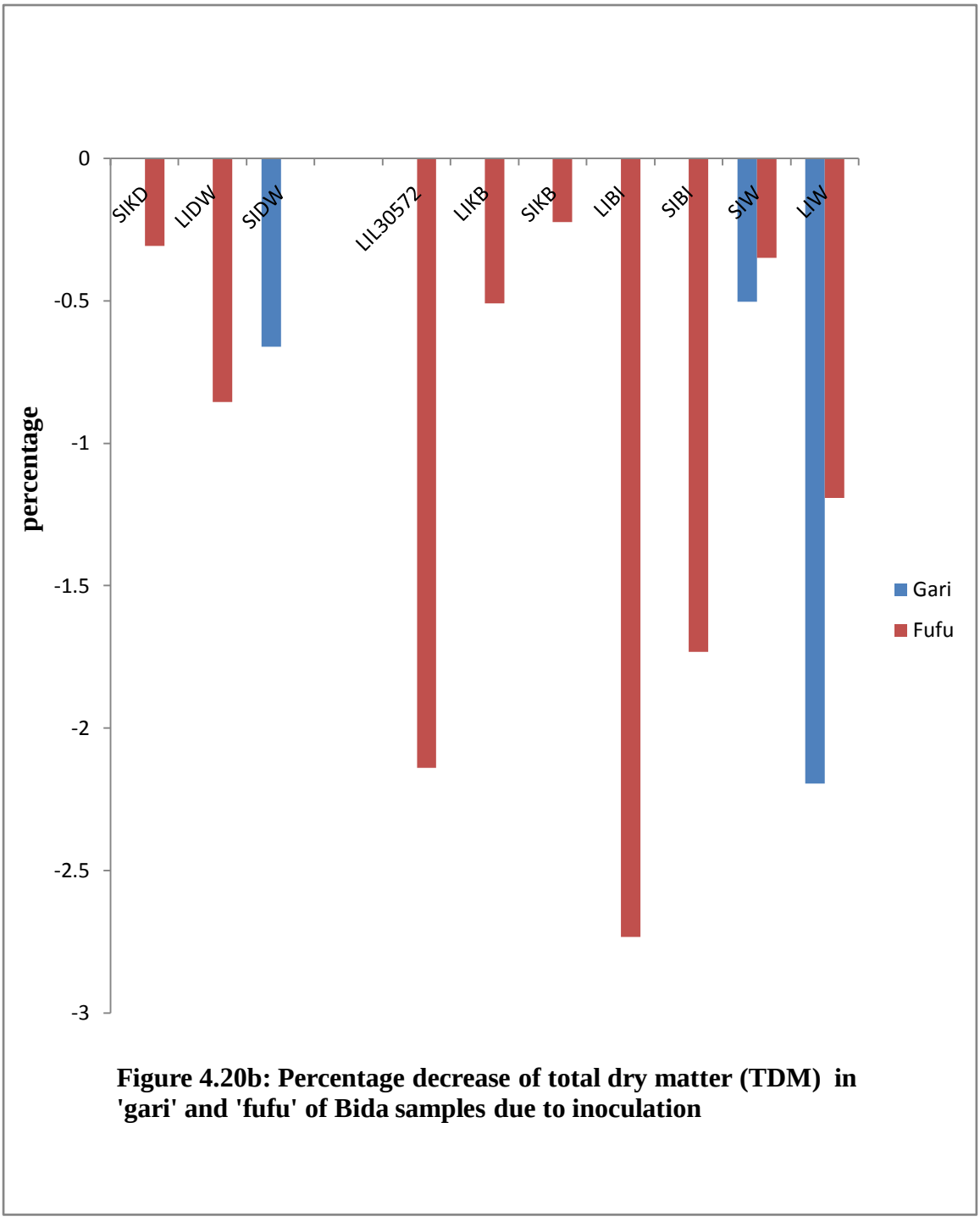


Figure 4.20b: Percentage decrease of total dry matter (TDM) in 'gari' and 'fufu' of Bida samples due to inoculation

The results of total dry matter (TDM) compositions in ‘fufu’ and ‘gari’ of Suleja samples fermented with the microbes are shown in Figures 4.21a and 4.21b. Also from the results, there was a discerned relationship between the microbial fermentation and TDM. The obvious trend of composition in Figures 4.21a and 4.21b was the existence of both percentage loss and increase respectively.

4.2 The Results of Percntage Decrease in Antinutrient Compostions of Cassava Products

The result of cyanide contents of ‘fufu’ and ‘gari’ products produced through microbial fermentation of selected varieties of cassava samples from Suleja site is presented in Figure 4.22. The percentage decrease in cyanide content was highest in Baba Iya’s *S. cerevisae*-treated ‘gari’ (70.43%) and lowest in ‘fufu’ produced from ‘Kpace Dzuru’ through *S. cerevisae* inoculation (2.85%).

Figure 4.23 presents the result of cyanide composition (percentage decrease) of the fermented cassava products - ‘gari’, ‘fufu’ subjected to microbial fermentation of Kontagora samples. The cyanide content decreases significantly ($P < 0.05$) after fermentation. Percentage reduction was highest in ‘gari’ fermented with *S. cerevisae* produced from ‘Baba Iya’ (68.64%) and lowest in ‘fufu’ treated with *L. bulgaricus* (1.01%).

The result of cyanogenic glycoside contents of fermented products of Bida samples is preseted in Figure 4.24. The highest percentage reduction was found in *L. bulgaricus* inoculated ‘fufu’ produced from TMS92/0326 (86.17%) and the leaest reduction occured in *S. cerevisae* treated ‘gari’ from TMS92/0326 (1.30%).

Figure 4.25 presents the result of oxalate contents of ‘fufu’ and ‘gari’ products obtained through microbial treatment of Suleja samples. The *S. cerevisae*-inoculated ‘gari’ produced from ‘Karimugi’ had the highest percentage increase (54.05%) when compared to the uninoculated counterparts. From the results, reduction in oxalate was more pronounced in ‘gari’ products.

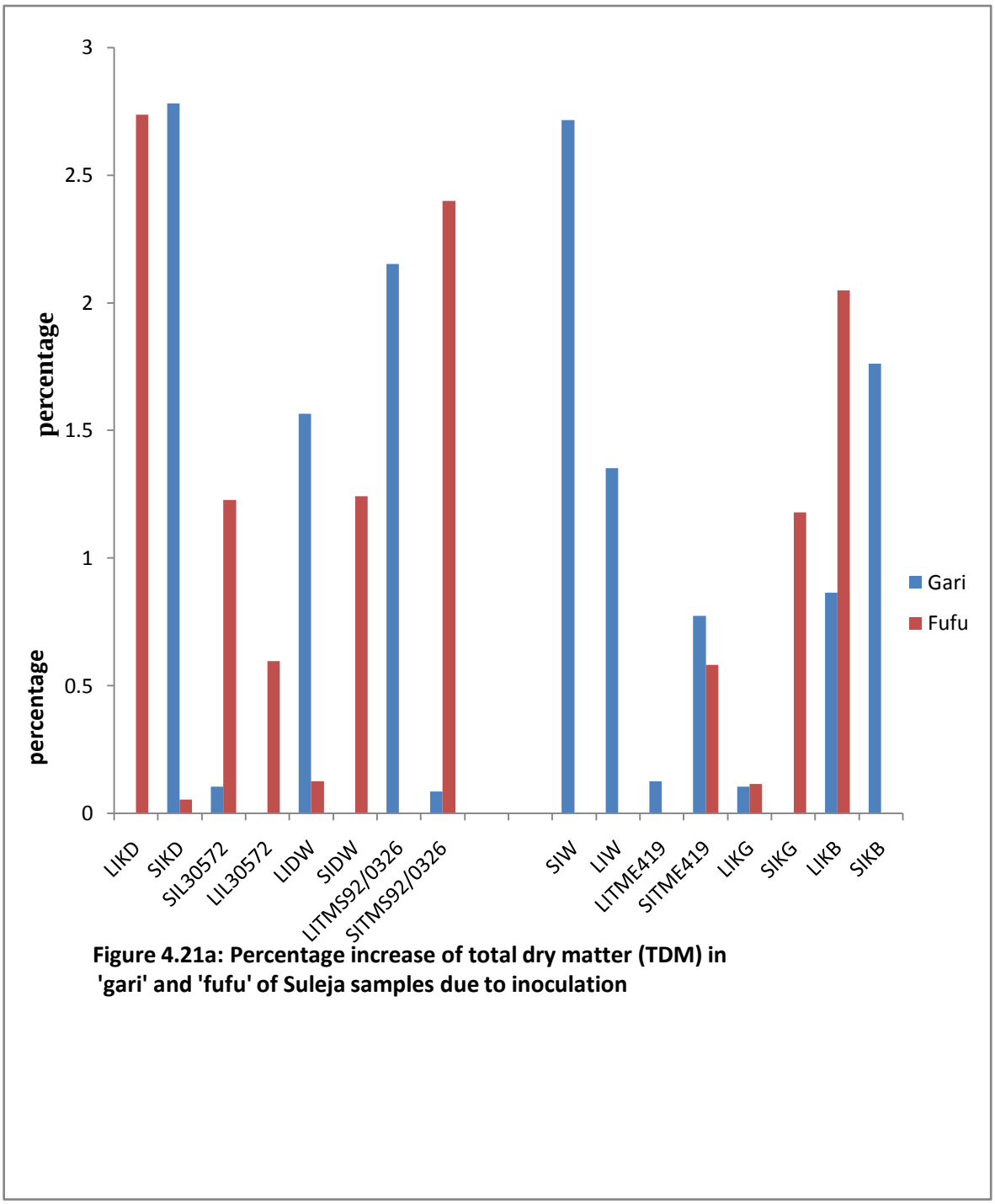


Figure 4.21a: Percentage increase of total dry matter (TDM) in 'gari' and 'fufu' of Suleja samples due to inoculation

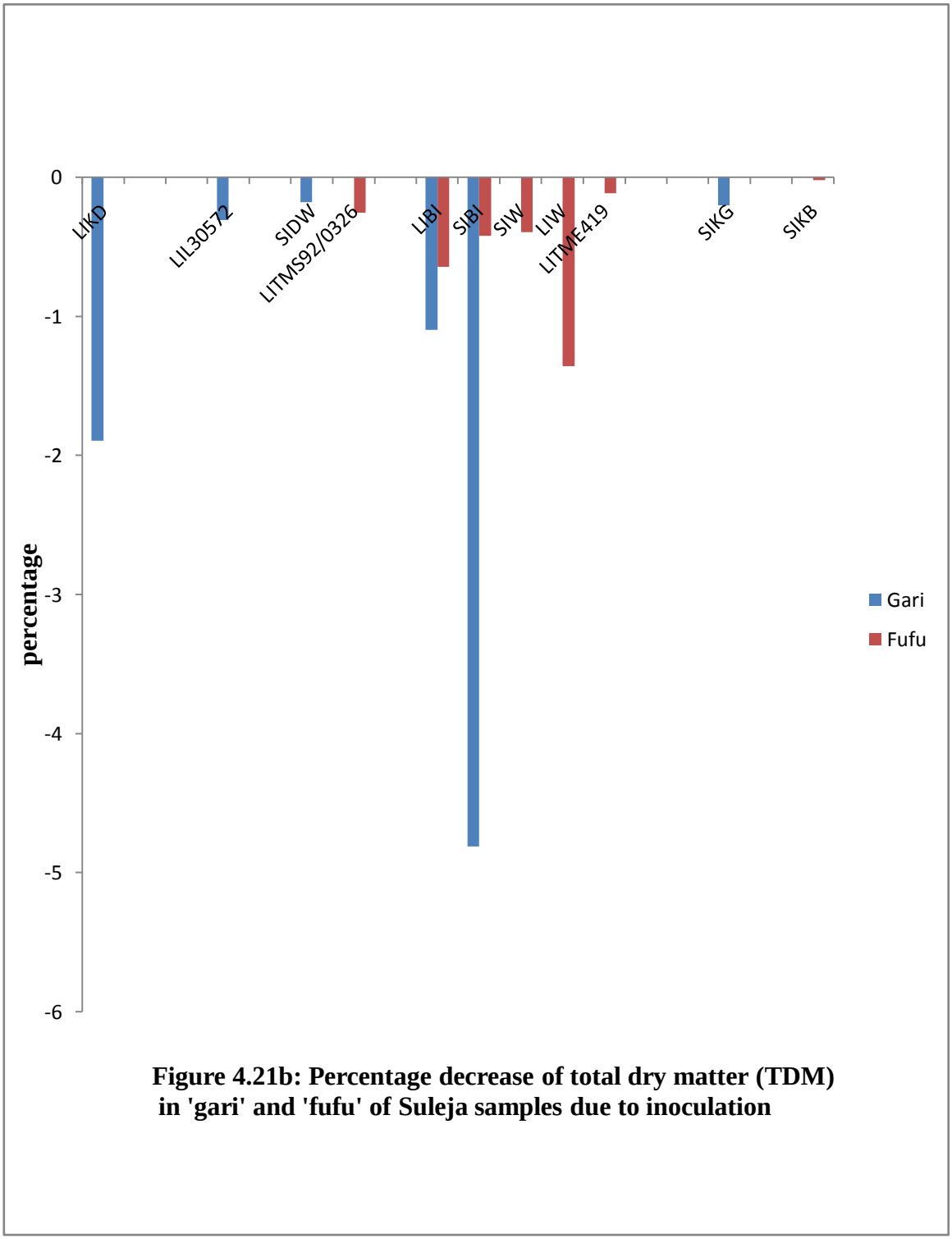


Figure 4.21b: Percentage decrease of total dry matter (TDM) in 'gari' and 'fufu' of Suleja samples due to inoculation

4.2 The results of percntage decrease in anti-nutrient compositions of cassava samples.

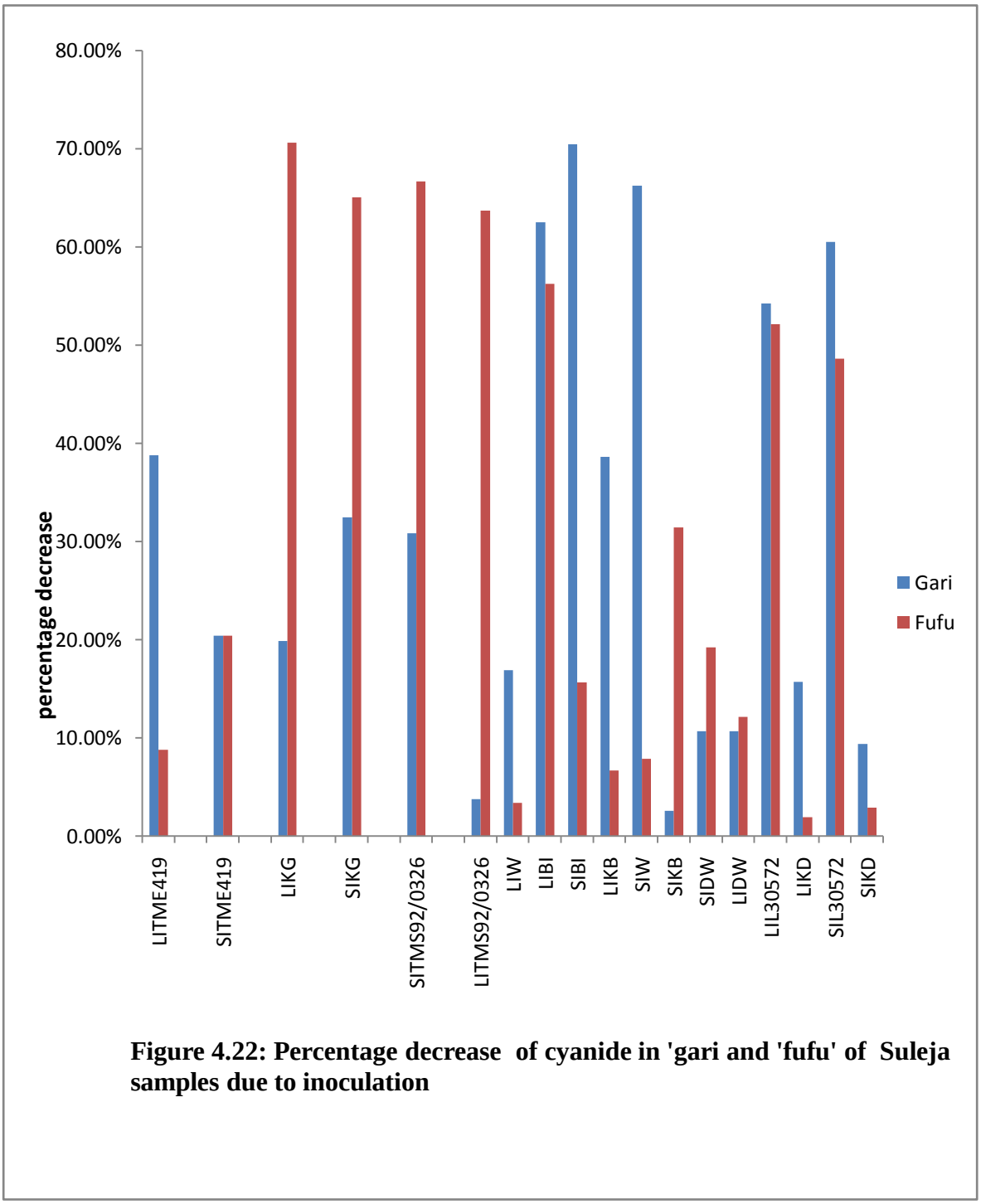


Figure 4.22: Percentage decrease of cyanide in 'gari and 'fufu' of Suleja samples due to inoculation

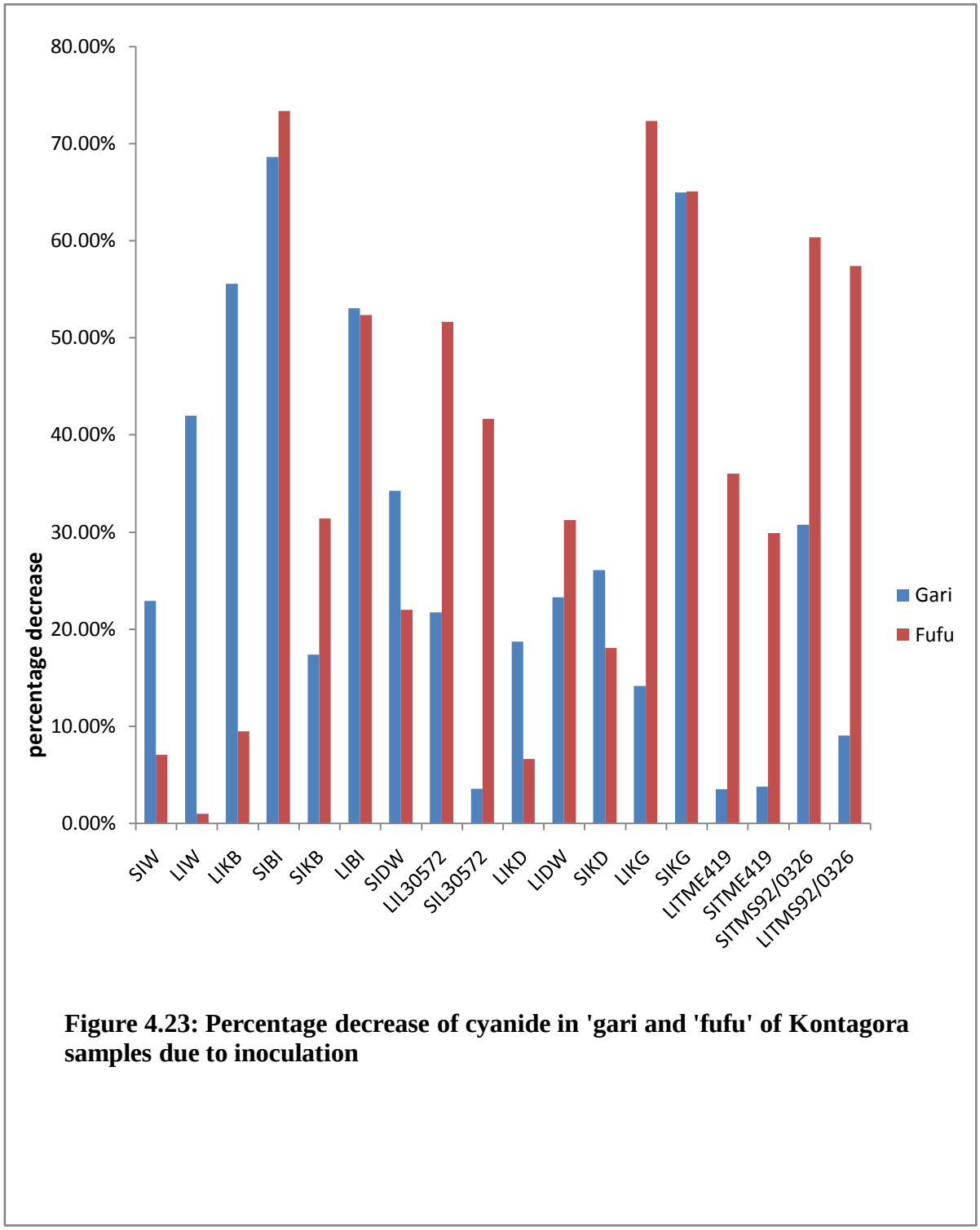


Figure 4.23: Percentage decrease of cyanide in 'gari and 'fufu' of Kontagora samples due to inoculation

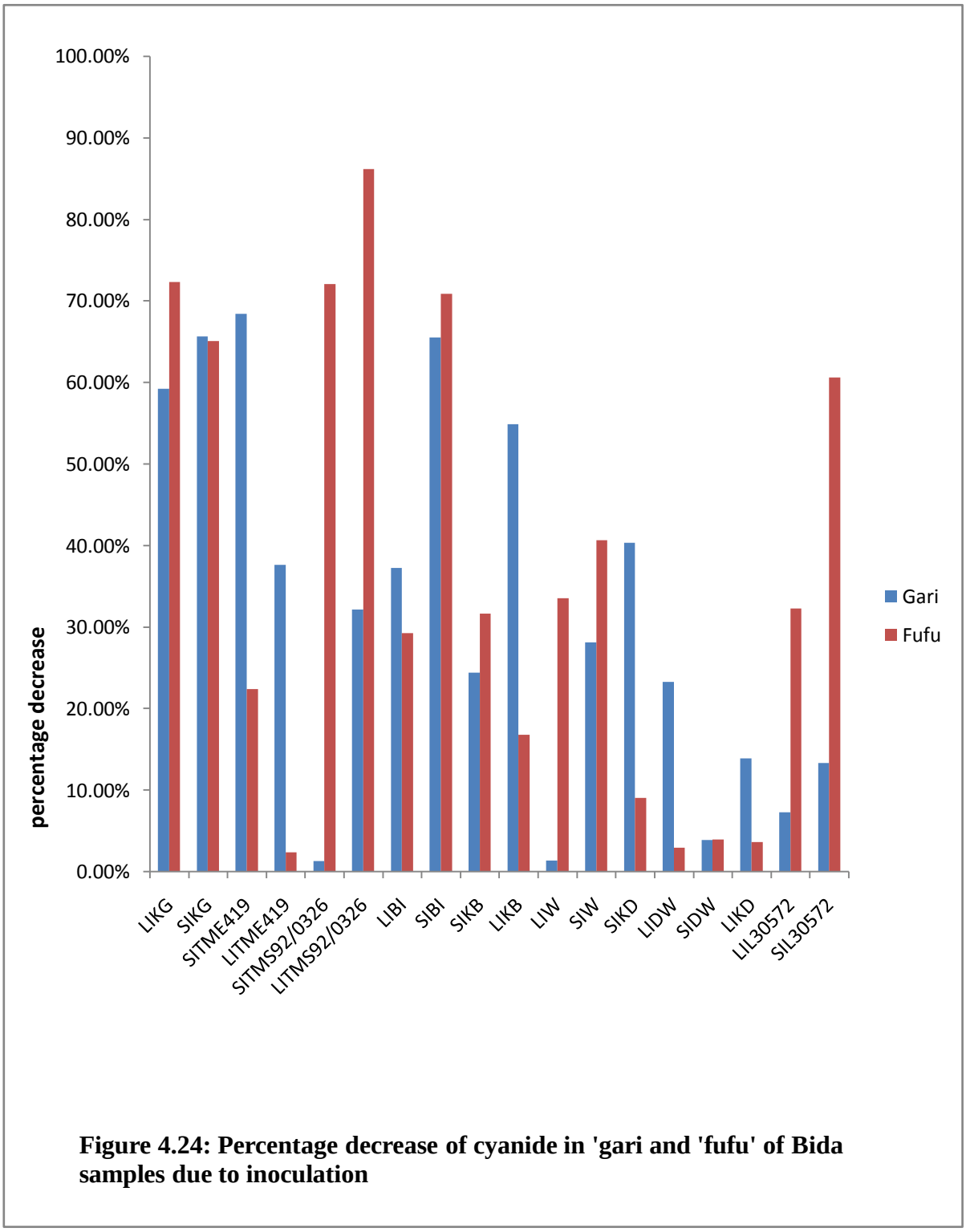


Figure 4.24: Percentage decrease of cyanide in 'gari and 'fufu' of Bida samples due to inoculation

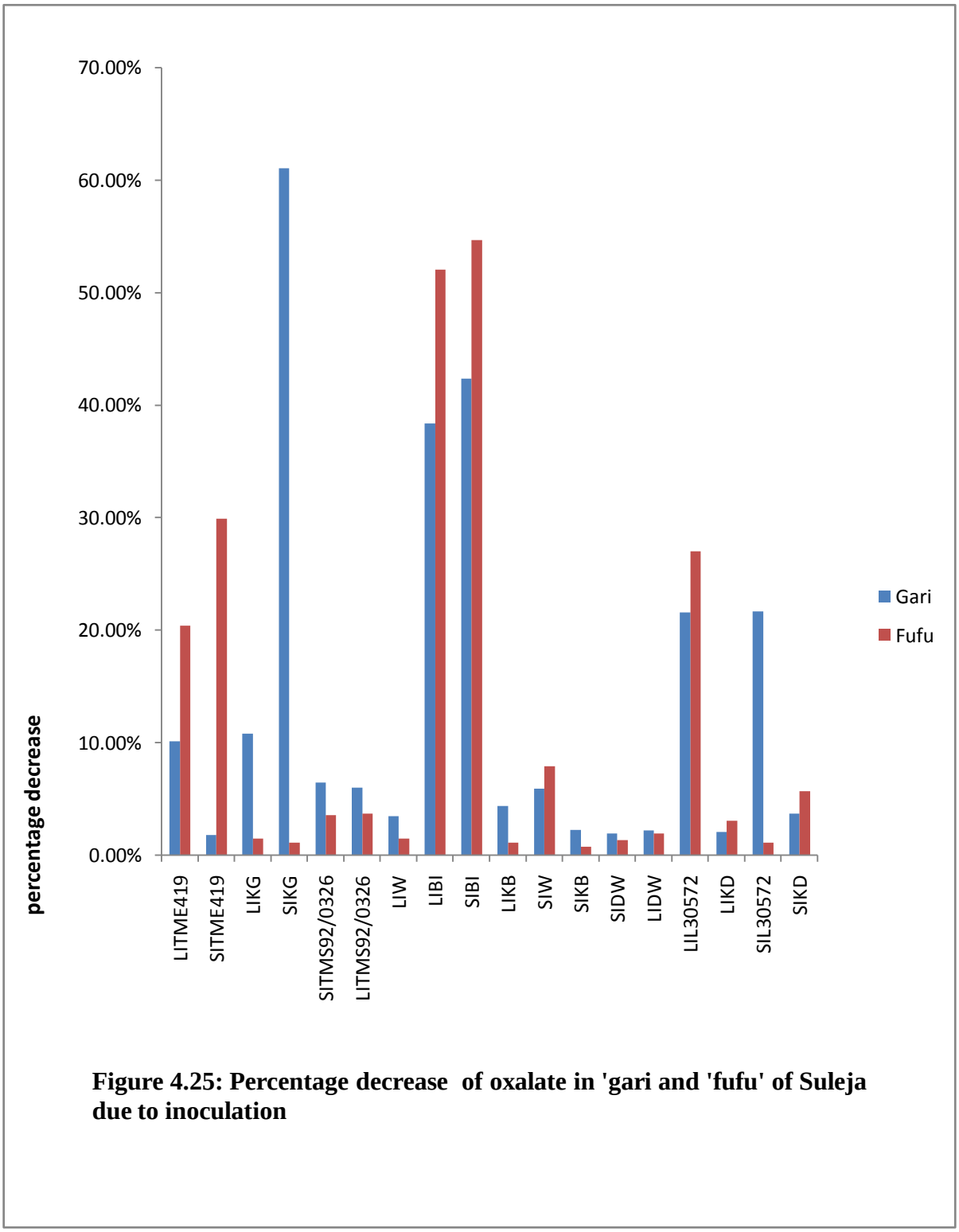


Figure 4.25: Percentage decrease of oxalate in 'gari and 'fufu' of Suleja due to inoculation

The result of the level of percentage decrease of oxalate in cassava products – 'fufu' and 'gari' – of Kontagora samples, inoculated separately with *S. cerevisae* and *L. bulgaricus* is presented in Figure 4.26. The *S. cerevisae*-fermented 'gari' produced from 'Karimugi' (49.11%) recorded the highest percentage oxalate reduction while the 'fufu' inoculated with *L. bulgaricus* obtained from *TME419* (0.76%) had the least percentage reduction in oxalate.

Figure 4.27 constitutes the result of oxalate percentage decrease in Bida samples microbially fermented ('fufu' and 'gari').

The levels of percentage decrease of phytate microbially fermented cassava products - 'fufu' and 'gari' – of Suleja samples are presented in Figure 4.28. It was observed from the results that the highest percentage reduction was recorded in TMS92/0326 cultivar's 'fufu' treated with *L. bulgaricus* (53.81%) and the least reduction was in 'gari' produced from 'Wahabi' through *L. bulgaricus* fermentation (1.91%).

Levels of percentage reduction in phytate in the microbially treated 'fufu' and 'gari' products of Kontagora samples are shown in Figure 4.29. The reduction in *S. cerevisae*- treated 'fufu' from 'Kpace Dzuru' was the highest (40.76%) and 'karimugi's *L. bulgaricus* fermented gari had the lowest reduction (0.78%).

The reduction in phytate for the 'fufu' and 'gari' products fermented from the Bida samples are presented in Figure 4.30. The highest value was recorded in *S. cerevisae*-fermented 'fufu' made from TMS92/0326 (72.03%).

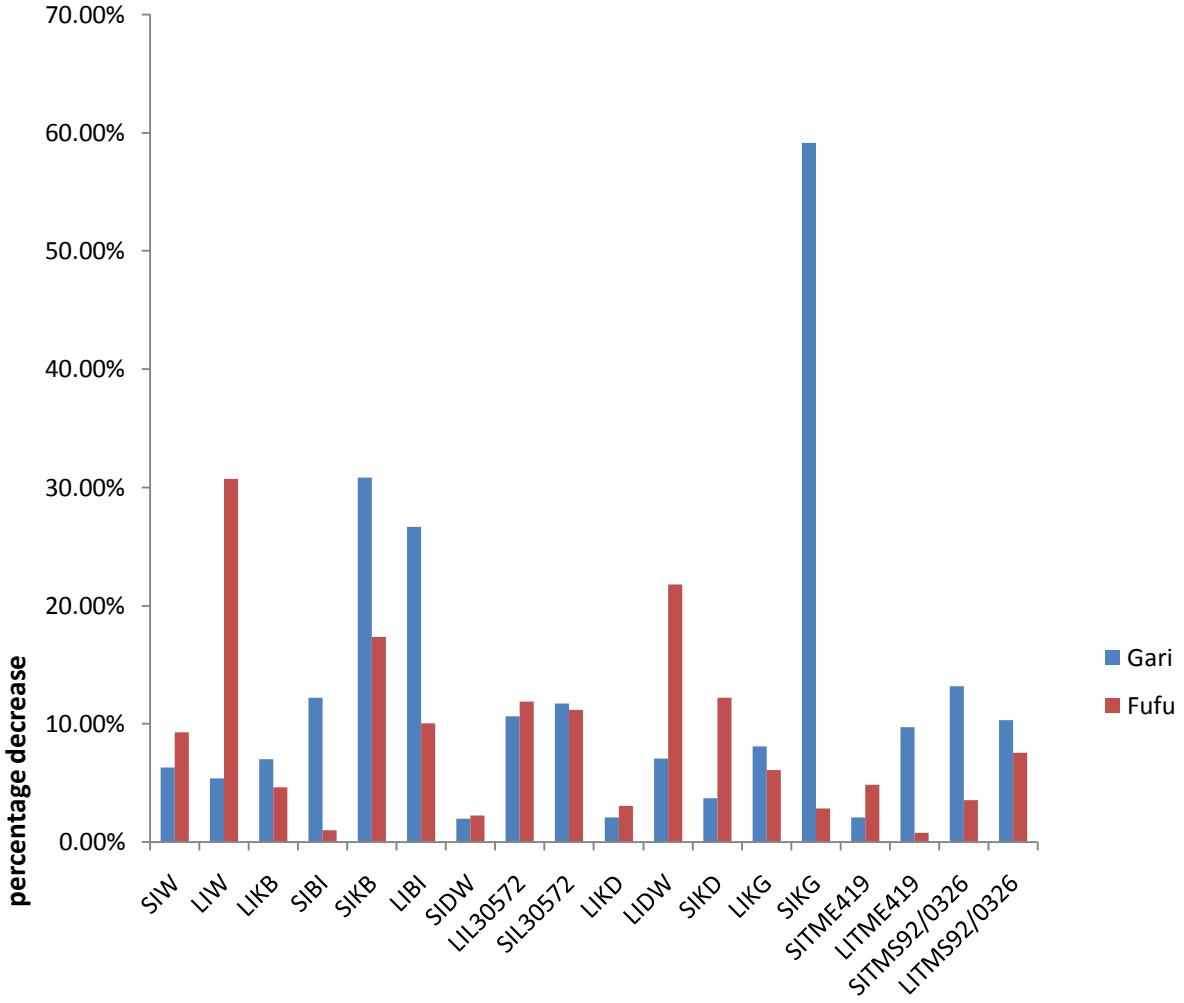


Figure 4.26: Percentage decrease of oxalate in 'gari and 'fufu' of Kontagora samples due to inoculation

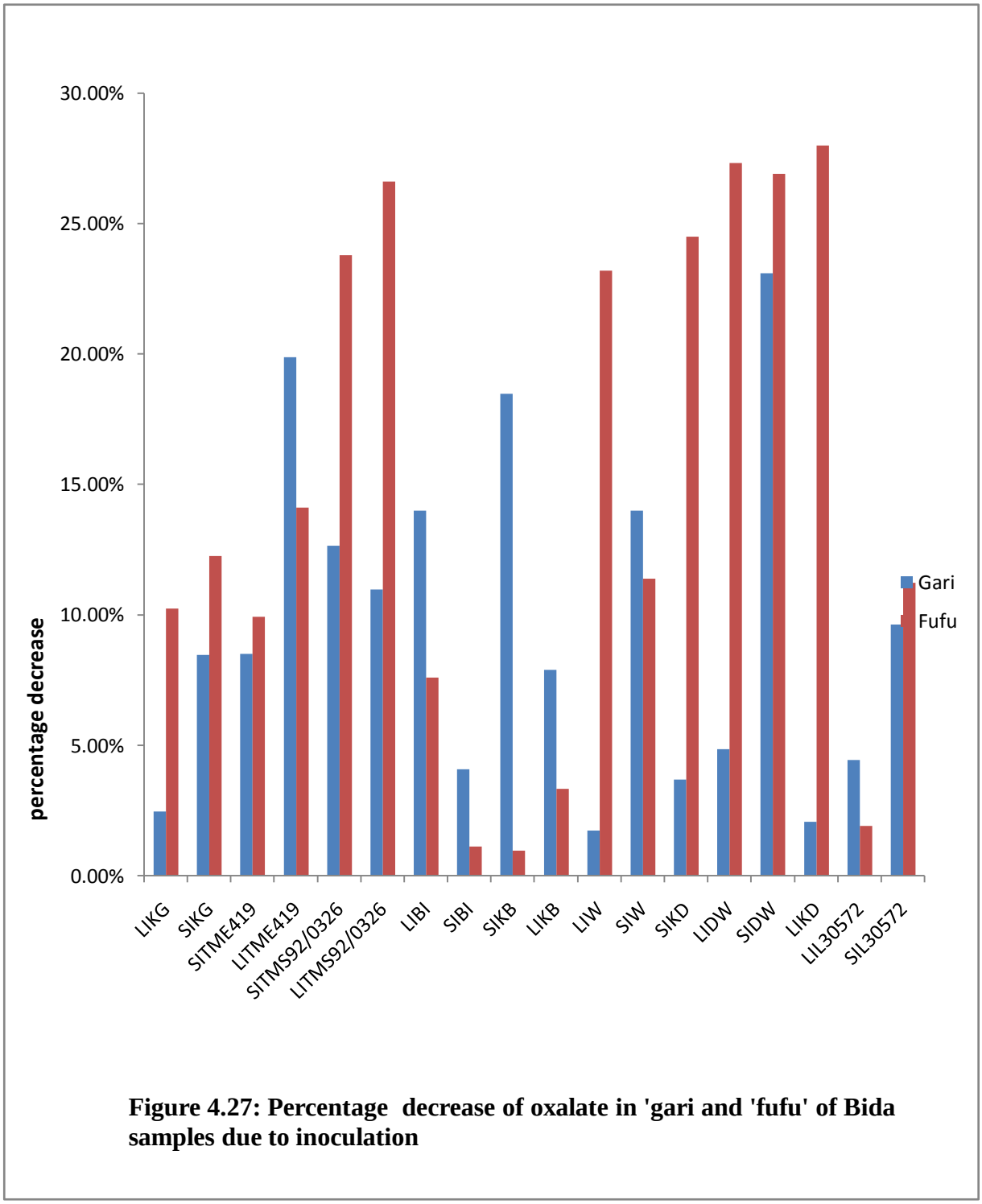


Figure 4.27: Percentage decrease of oxalate in 'gari and 'fufu' of Bida samples due to inoculation

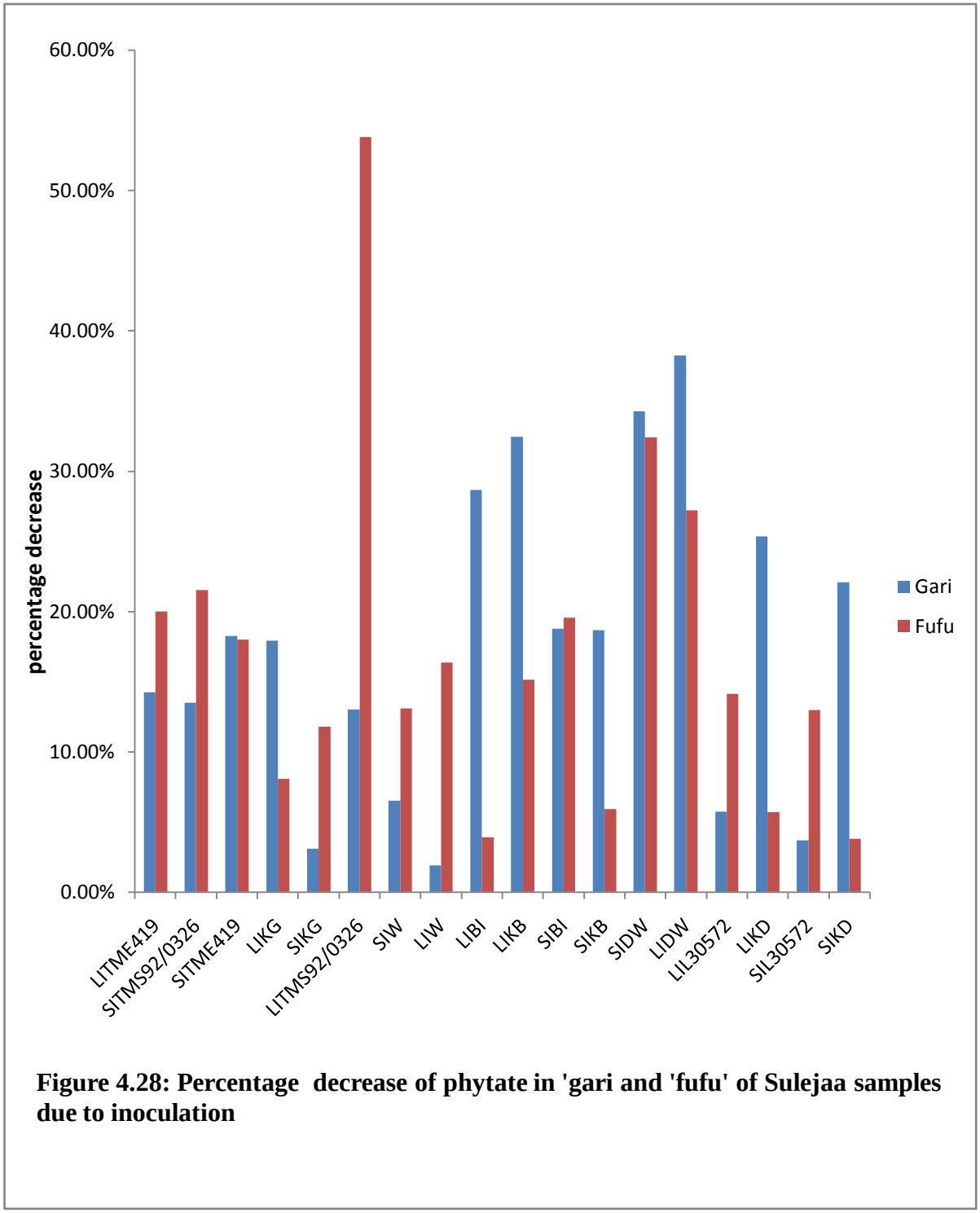


Figure 4.28: Percentage decrease of phytate in 'gari and 'fufu' of Sulejaa samples due to inoculation

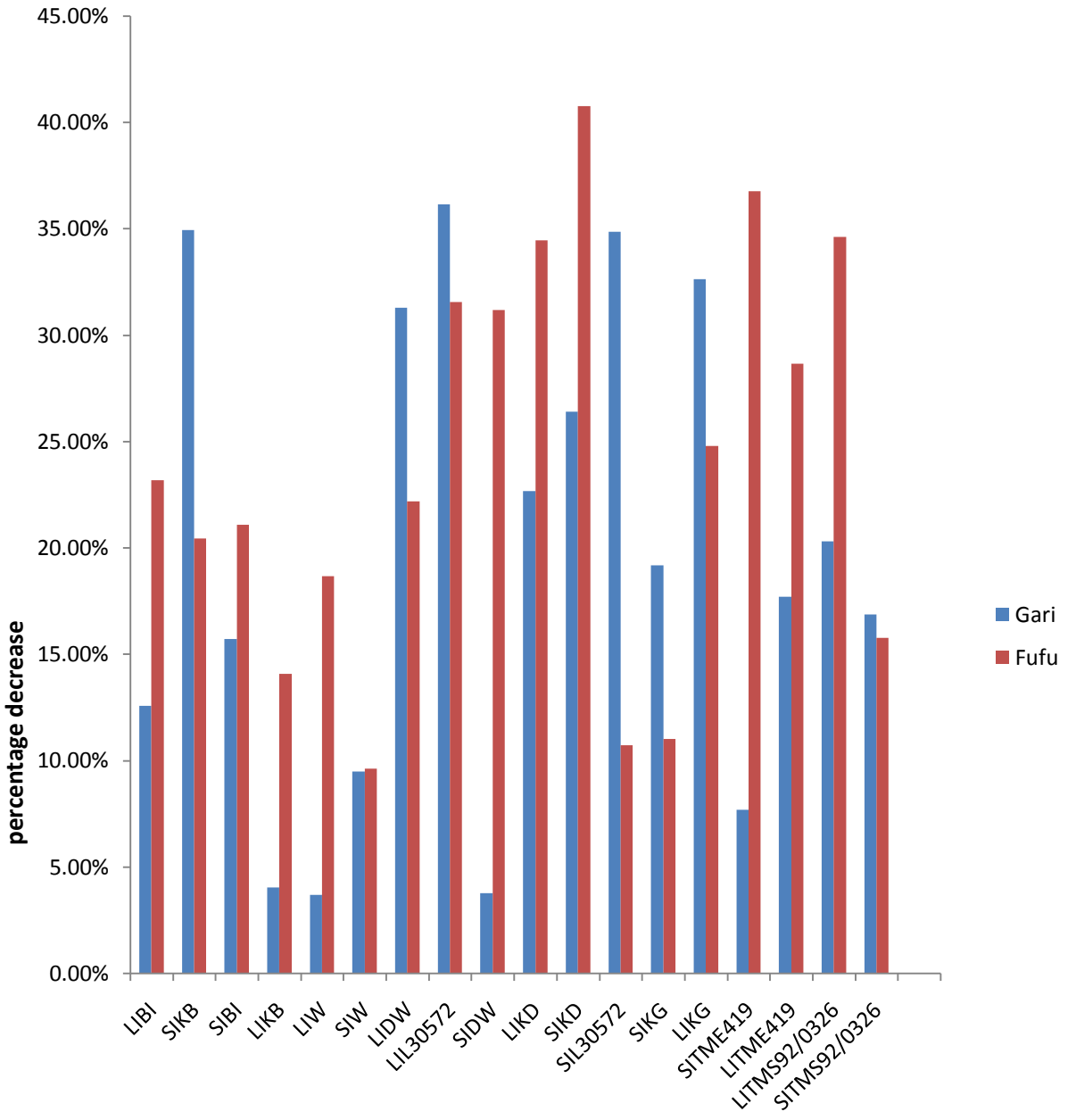


Figure 4.29: Percentage decrease of phytate in 'gari and 'fufu' of Kontagora samples due to inoculation

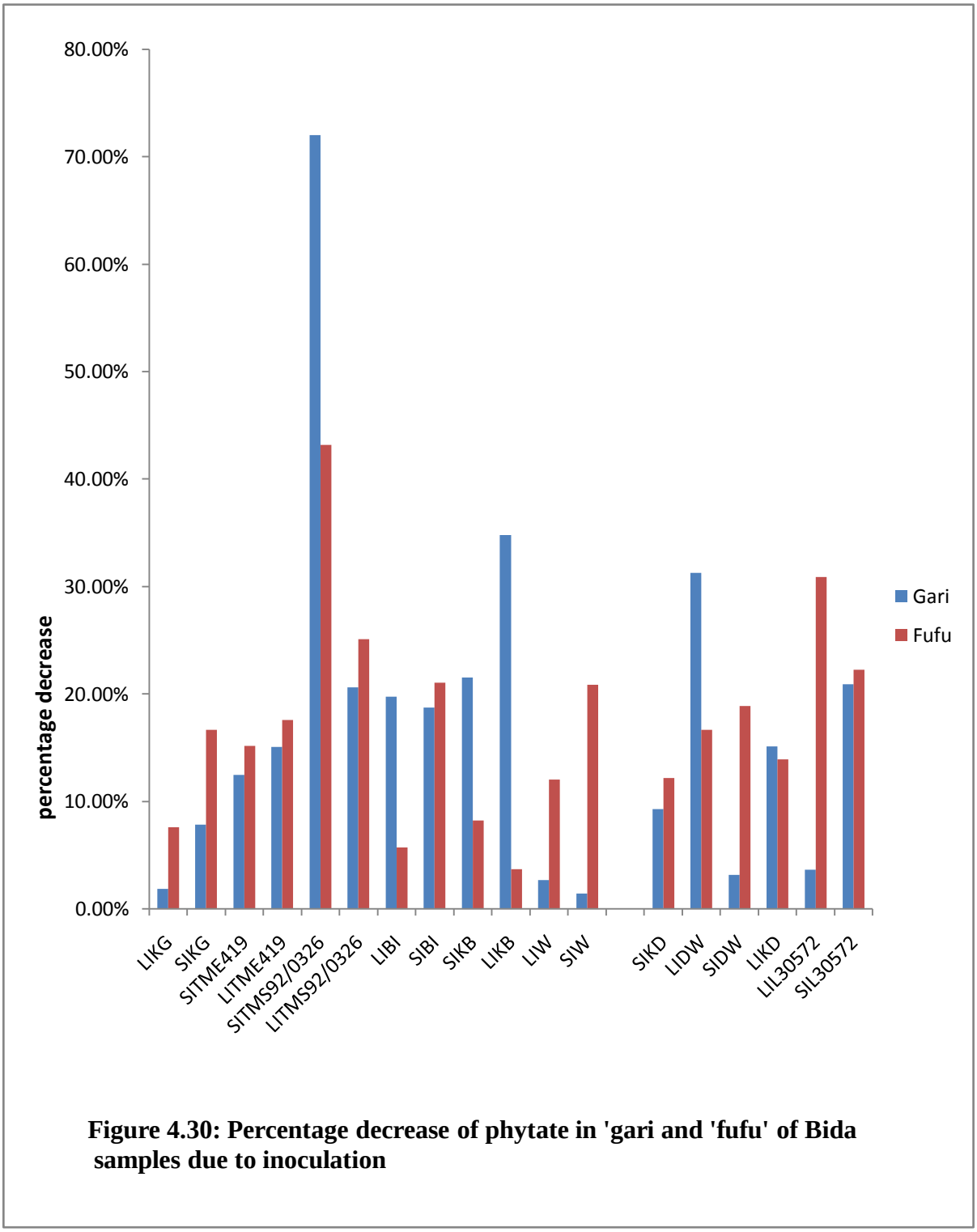


Figure 4.30: Percentage decrease of phytate in 'gari and 'fufu' of Bida samples due to inoculation

Figure 4.31 presents the of tannin contents of the microbially fermented 'fufu' and 'gari' products obtained from various cassava varieties cultivated at Suleja area. The reductions were markedly high in *L. bulgaricus*-treated 'fufu' from TMS92/0326 (34.67%), *S. cerevisae*-inoculated 'gari' from 'Kpace Bokun' (33.86%), 'wahabi' (30.33%), *L. bulgaricus*-treated 'gari' produced from 'Wahabi' (47.81%), 'Baba Iya' (33.27%).

The result of tannin contents obtained for Kontagora cassava samples microbial fermented to 'gari' and 'fufu' is presented in Figure 4.32. Tannin content recorded the highest percentage reduction in TME419's *S. cerevisae*-treated 'fufu' (36.76%) and the lowest reduction was in 'gari' inoculated with *L. bulgaricus* from 'Baba Iya' (0.67%).

Figure 4.33 shows the result of the reduction of tannin in 'gari' and 'fufu' products being microbially fermented using various varieties of cassava cultivated at Bida sampling site. The highest decrease occured in *L. bulgaricus*-inoculated 'gari' produced from TMS92/0326 (47.74%) and *L. bulgaricus*-fermented 'fufu' from 'Baba Iya' (48.14%), and the lowest reduction in tannin was recorded in *S. cerevisae* treated 'gari' obtained from 'Karimugi' (6.92%).

The result of saponin contents of 'fufu' and 'gari' products produced from cassava samples of Suleja sampling point is presented in Figure 4.34. The result indicated significant reduction in 'gari' produced from 'Kpace Dzuru' and 'Dan Warri' through *L. bulgaricus* treatment (53.82% and 42.26% respectively).

Figure 4.35 represents the saponin contents for 'fufu' and 'gari products produced through microbial treatments obtained from Kontagora samples. When considering the saponin content, the highest reduction occured *in S. cerevisae* inoculated fufu from 'Dan Warri' (52.29%) and the least reduction was in 'gari' treated with *L. bulgaricus* (2.43%).

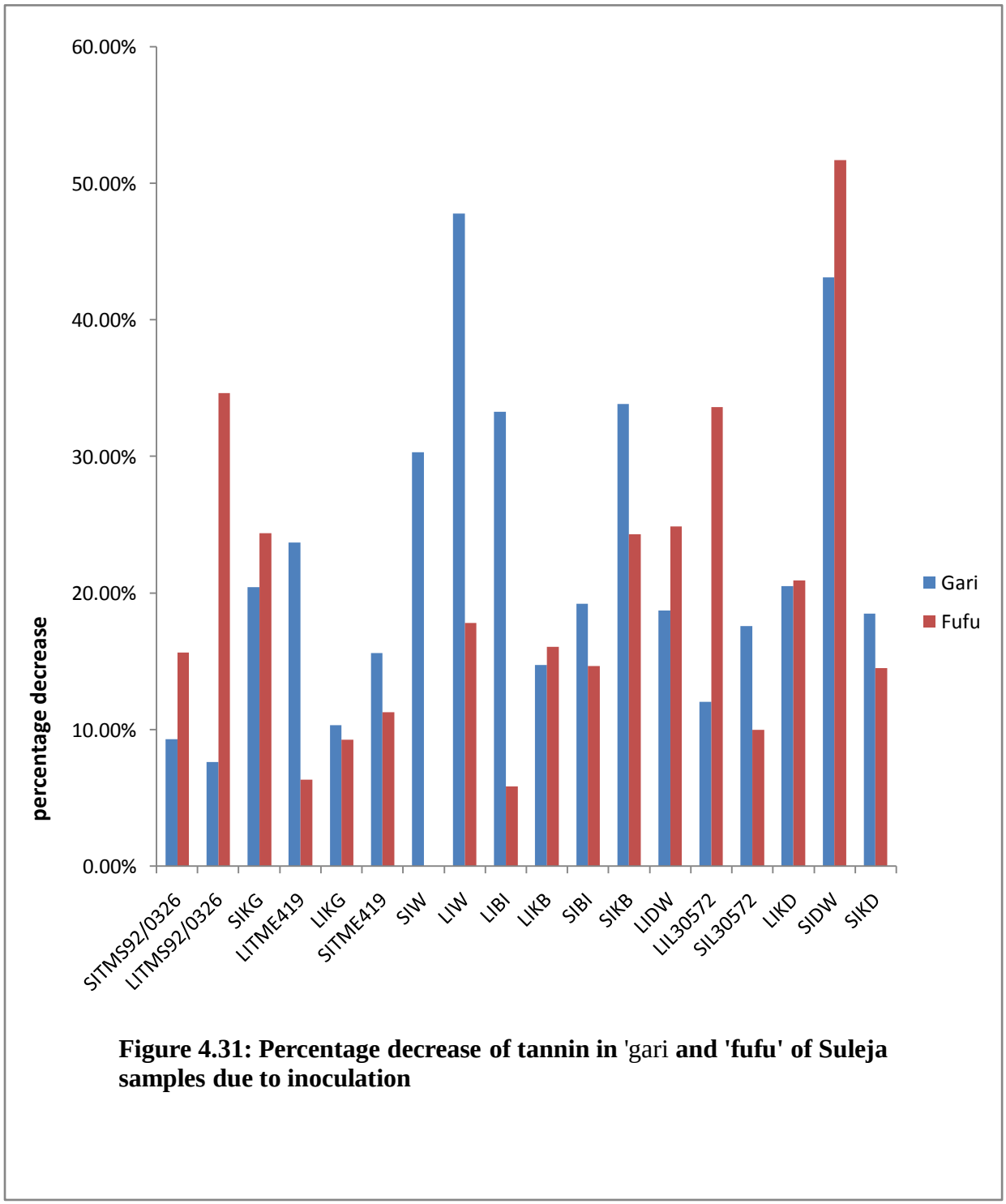


Figure 4.31: Percentage decrease of tannin in 'gari **and 'fufu' of Suleja samples due to inoculation**

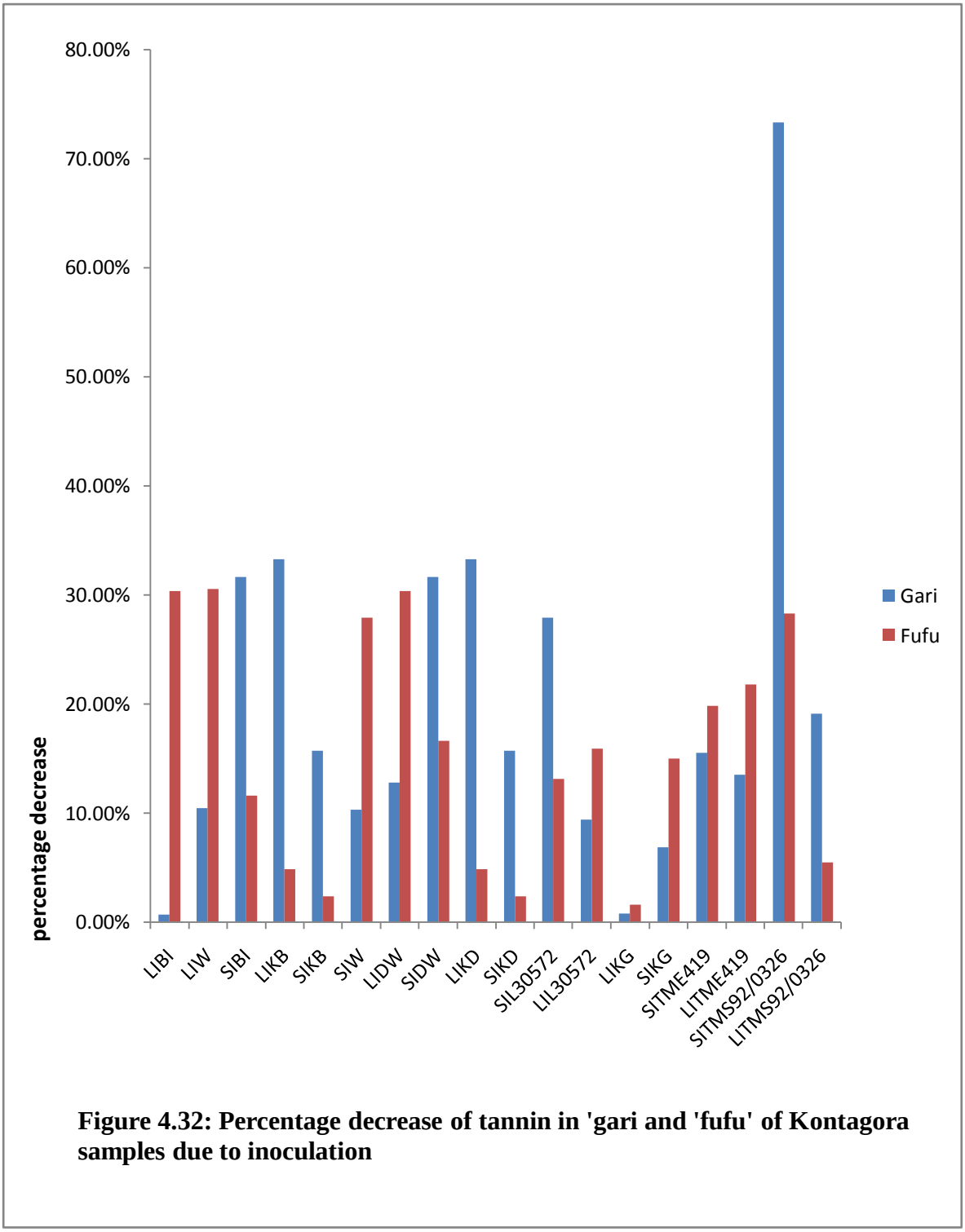


Figure 4.32: Percentage decrease of tannin in 'gari and 'fufu' of Kontagora samples due to inoculation

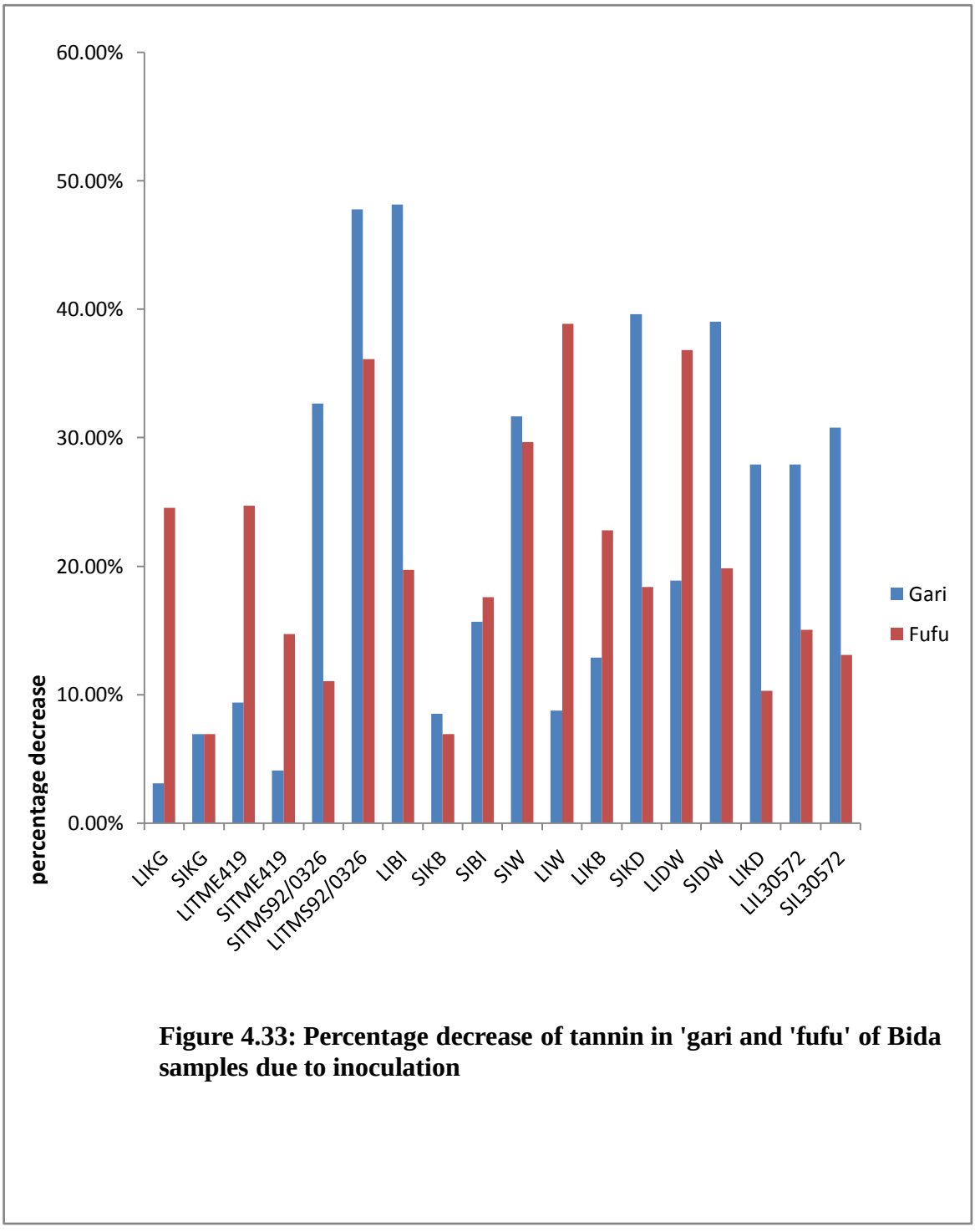


Figure 4.33: Percentage decrease of tannin in 'gari and 'fufu' of Bida samples due to inoculation

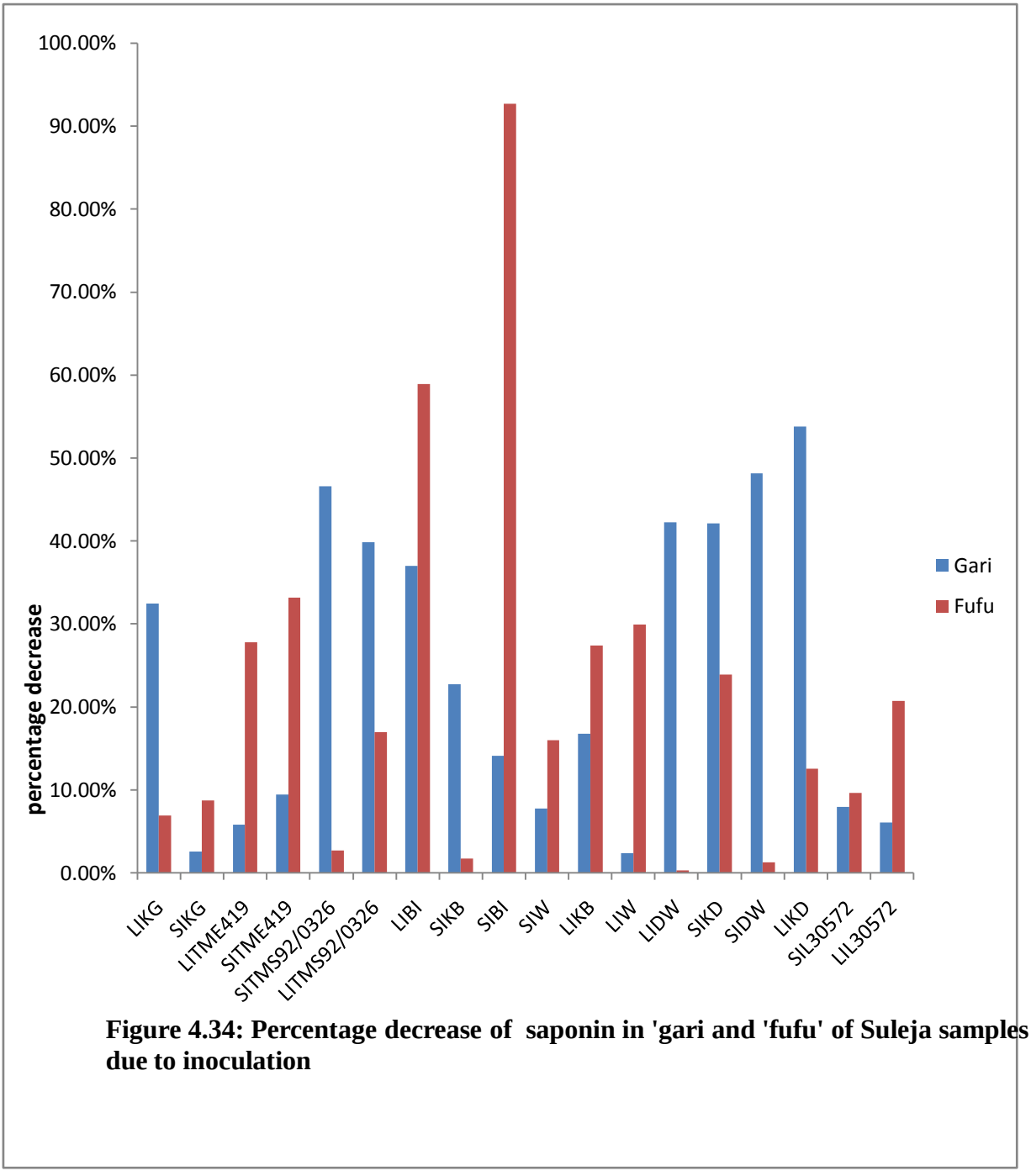


Figure 4.34: Percentage decrease of saponin in 'gari and 'fufu' of Suleja samples due to inoculation

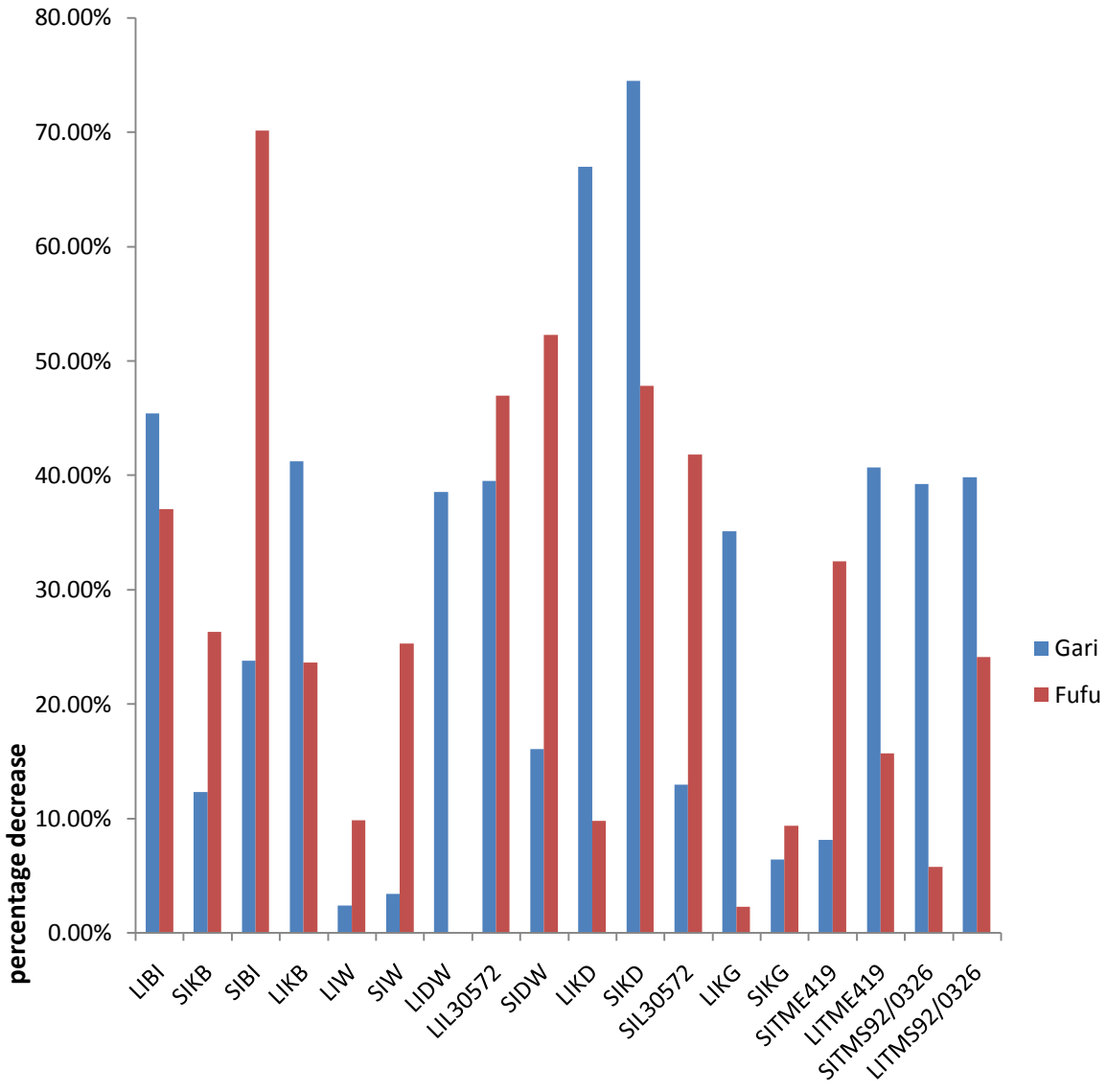


Figure 4.35: Percentage decrease of saponin in 'gari and 'fufu' of Kontagora samples due to inoculation

The result of saponins for ‘fufu’ and ‘gari products produced through microbial treatments obtained from Kontagora samples is presented in Figure 4.36. The highest reduction occured *in L. bulgaricus*–inoculated (66.60%) ‘gari’ from ‘kpace bokun’ and the lowest value found in ‘fufu’ treated with *L. bulgaricus* produced from ‘kpace dzuru’ (0.86%).

4.3 The results of percentage increase in elemental compositions of cassava samples

The result of the increase in the level of zinc in the microbial fermented products – ‘fufu’ and ‘gari’- obtained from Suleja cassava samples is presented in Figure 4.37. It was observed that *S. cerevisae*-treated ‘fufu’ product made from L30572 had 53.59% percentage increase and *L. bulgaricus*-fermented ‘fufu’ produced from L30572 recorded 48.57% increase.

The result of the level of zinc percentage increase of the microbial fermented products – ‘fufu’ and ‘gari’- obtained from Kontagora cassava samples is presented in Figure 4.38. It showed that the *S. cerevisae*-treated ‘fufu’ product made from ‘Kpace Dzuru increased by 27.41% and *L. bulgaricus*-fermented ‘fufu’ produced from ‘Kpace Dzuru’ had 20.00% increase.

The result of the percentage increase of zinc in the microbially fermented products – ‘fufu’ and ‘gari’- obtained from Bida cassava samples is presented in Figure 4.39. It was observed that both ‘fufu’ and ‘gari’ products appeared to show no appreciable difference in thier efficiency to get enriched with zinc, particularly for the *S. cerevisae*-treated ‘fufu’ product made from L30572 (20.18%) and *L. bulgaricus*-fermented ‘fufu’ produced from L30572 (14.09%).

Figure 4.40 presents the result of magnesium contents in “fufu’ and ‘gari’ obtained from Suleja sampling site. The increase in percantage of magnesium in the ‘gari’ product inoculated with *S. cerevisae* and produced from TMS92/0326 had the highest vlaue of 68.64% and the ‘fufu’ fermented with *L. bulgaricus* obtained from TME419 recorded the lowest amount of (1.92%).

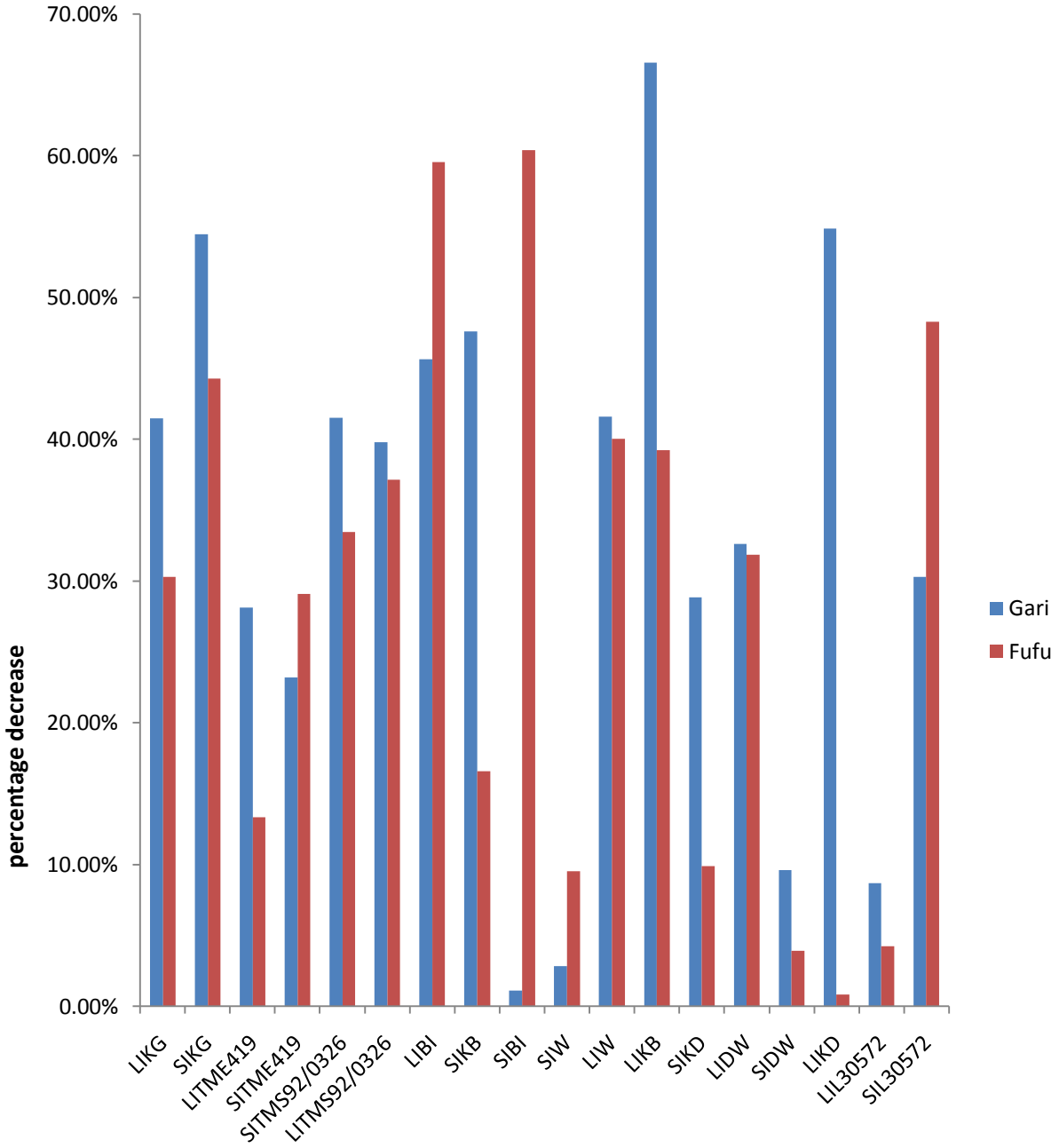


Figure 4.36: Percentage decrease of saponin in 'gari and 'fufu' of Bida samples due to inoculation

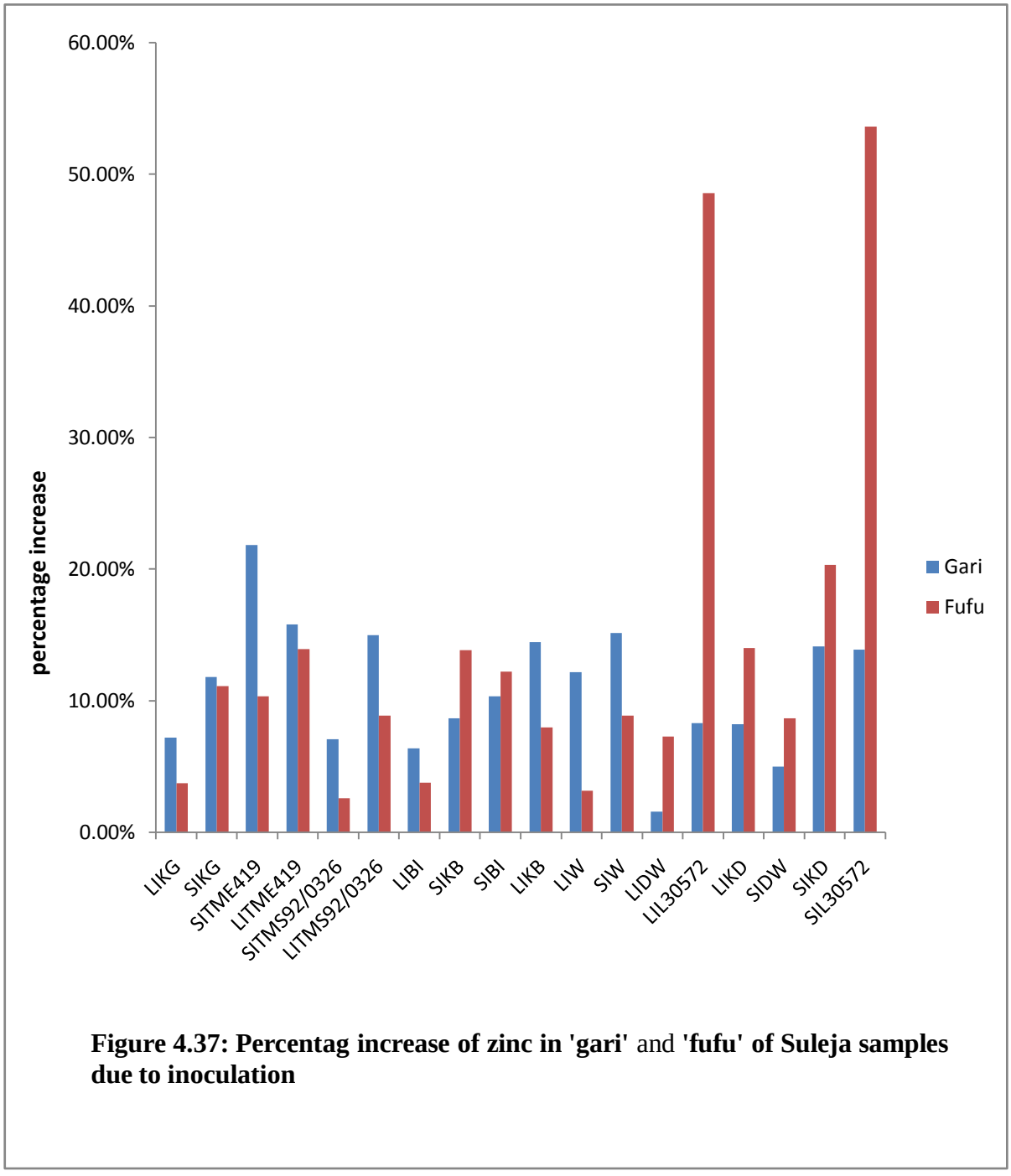


Figure 4.37: Percentag increase of zinc in 'gari' and **'fufu' of Suleja samples due to inoculation**

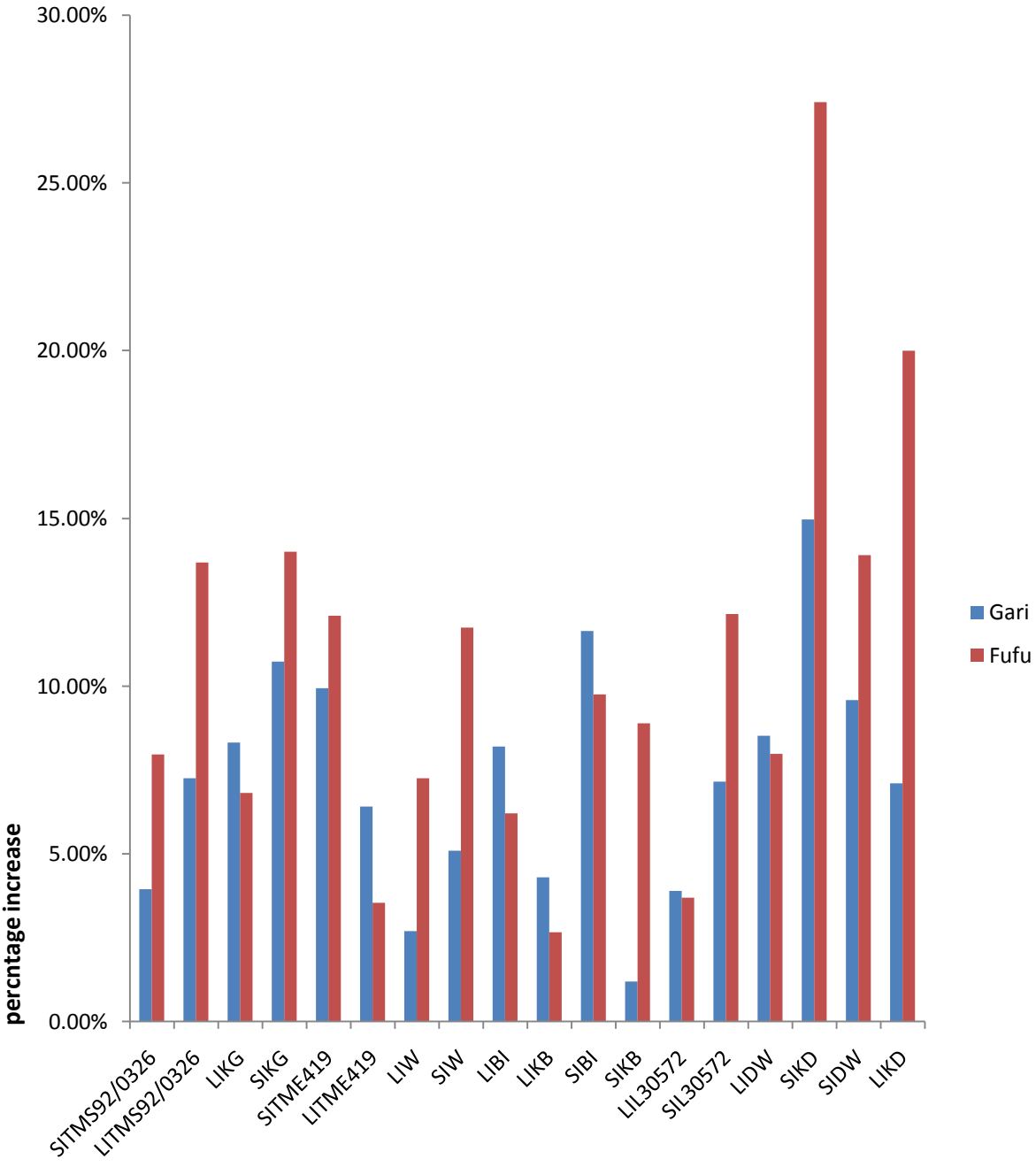


Figure 4.38: percentage increase of zinc in 'gari and 'fufu' of Kontagora samples due to inoculation

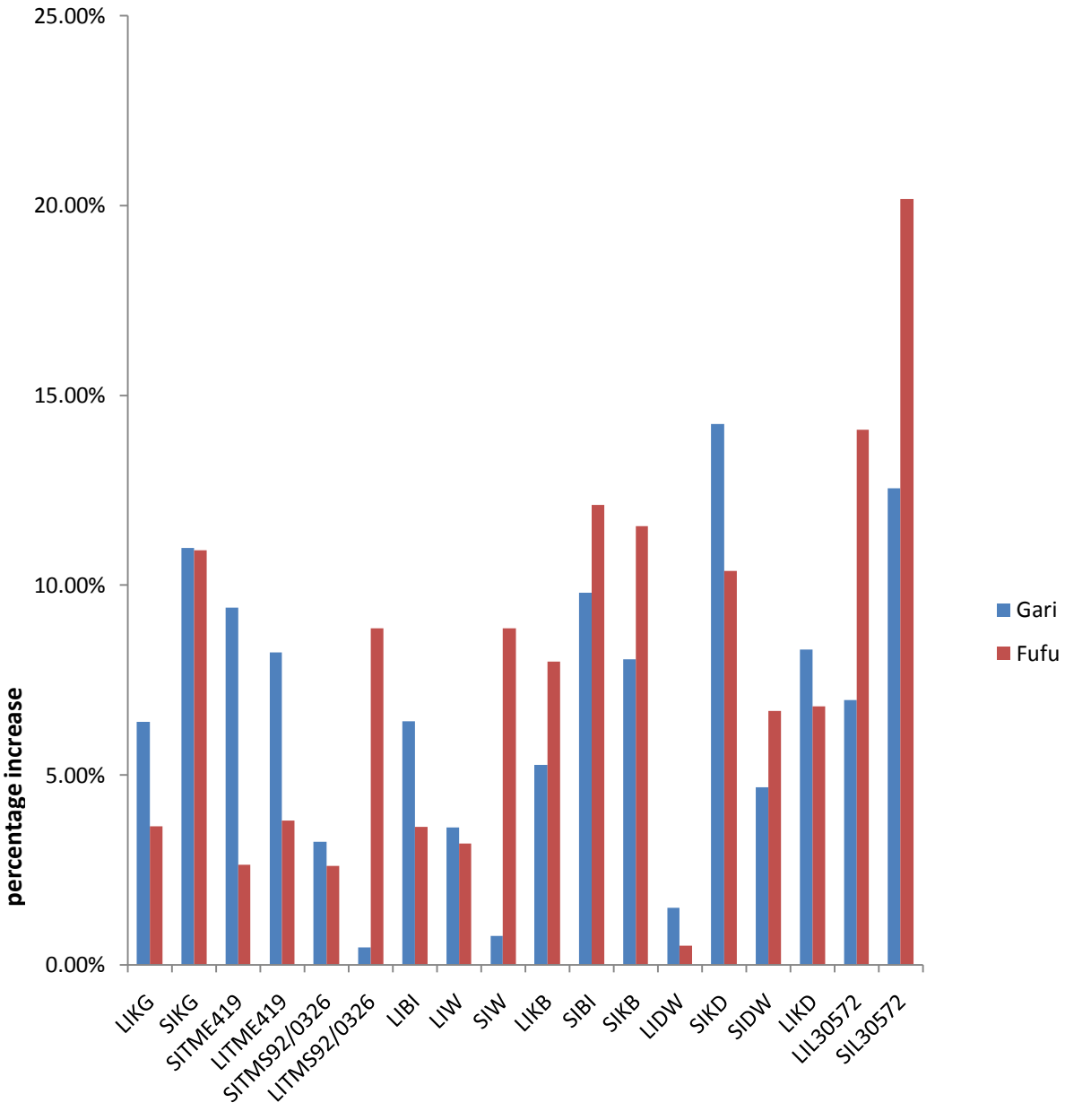


Figure 4.39: Percentage increase of zinc in 'gari and 'fufu' of Bida samples due to inoculation

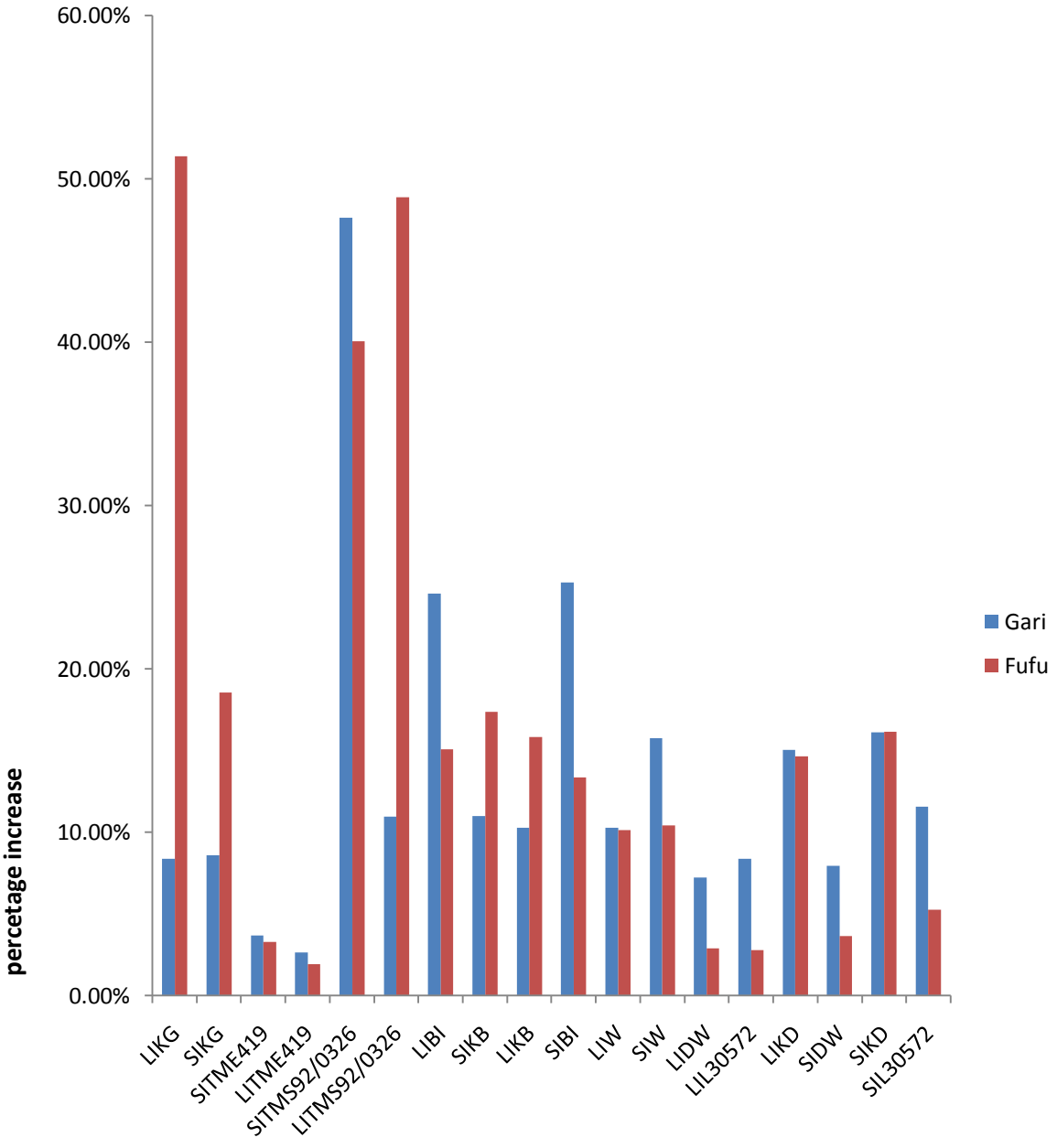


Figure 4.40: Percentage increase of magnesium in 'gari and 'fufu' of Suleja samples due to inoculation

Figure 4.41 presents the result of magnesium contents in "fufu' and 'gari' obtained from Kontagora sampling area, and subjected to microbial treatments. The percentage increase of magnesium was highest in 'fufu' produced through *L. bulgaricus* fermentation of 'baba iya' (42.37%) and was least in 'fufu' made from Dan Warri and inoculated with *S. cerevsae (*1.60%).

The result of magnesium contents in cassava-based products – "fufu' and 'gari' obtained from Bida sampling site, and subjected to microbial treatments is presented in Figure 4.42. From the result, percentage increase in magnesium was reasonably high in 'gari' and 'fufu' (48.36% and 55.15% respectively) obtained from TME419 through *S. cerevisae* fermentation,

The level of percentage increase of sodium in 'fufu' and 'gari products of Suleja samples is presented in Figure 4.43. A highest value of 51.67% was recorded in 'fufu' produced from 'Karimugi' through *L. bulgaricus* fermentation and a least value of 0.89% for 'gar' produced from 'Kpace bokun' subjected to *S. cerevisae* fermentation.

The percentage increase of sodium in 'fufu' and 'gari obtained for Kontagora samples are presented in Figure 4.44. The highest percentage of sodium increase of 24.53% was in 'fufu' product of TMS92/0326 treated with *L. bulgaricus* and the lowest value of 1.19% found in 'gari' made from K pace Bokun through *S. cerevisae* fermentation.

The result of increase in percentage of sodium in microbial fermented cassava products obtained from Bida sampling area is presented in Figure 4.45. These values of sodium ranged from 0.74% for 'gari' produced from 'dan warri' through *S. cerevisae* fermentation to 56.06% for 'fufu' made from 'kpace dzuru treated with *L. bulgaricus.*

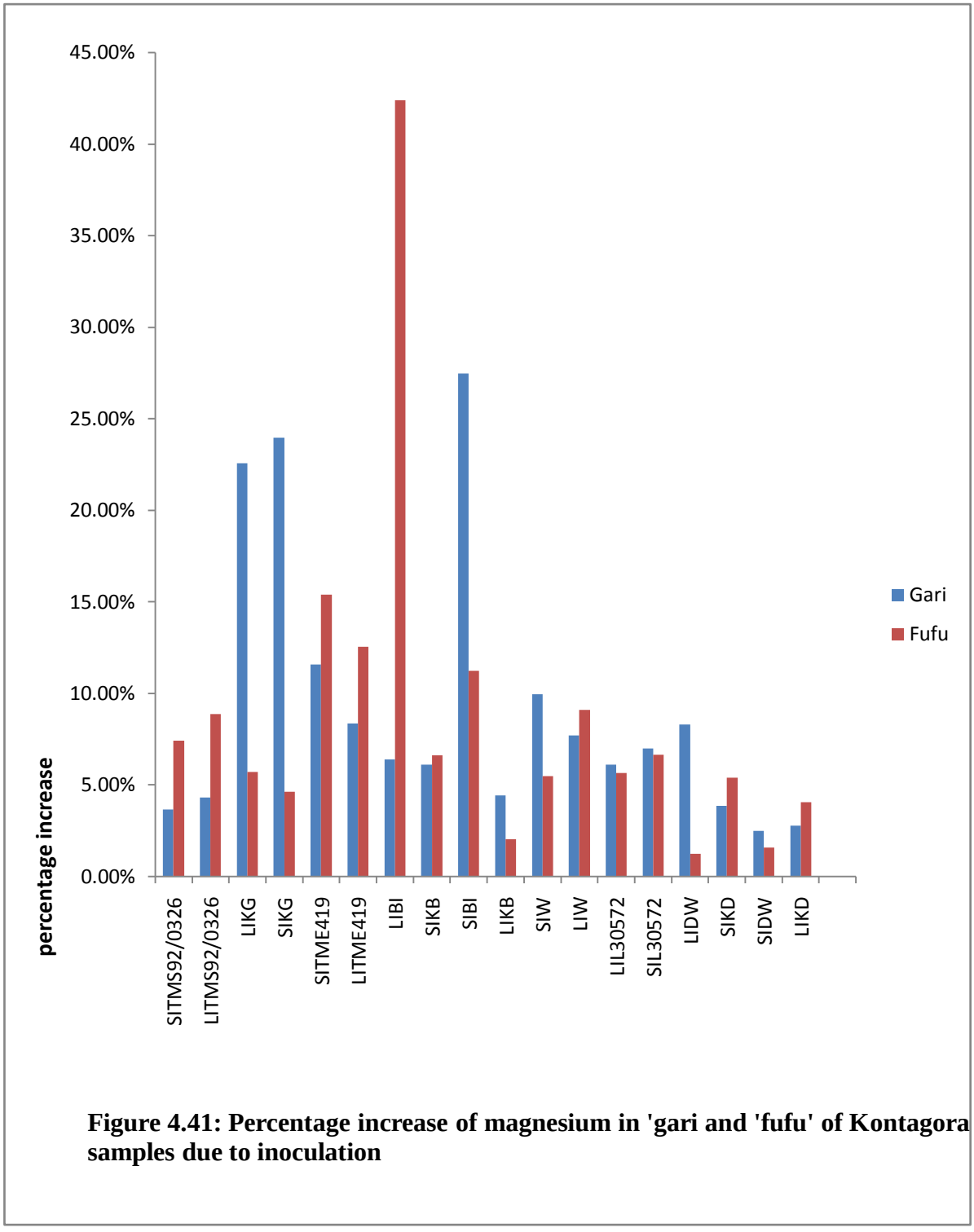


Figure 4.41: Percentage increase of magnesium in 'gari and 'fufu' of Kontagora samples due to inoculation

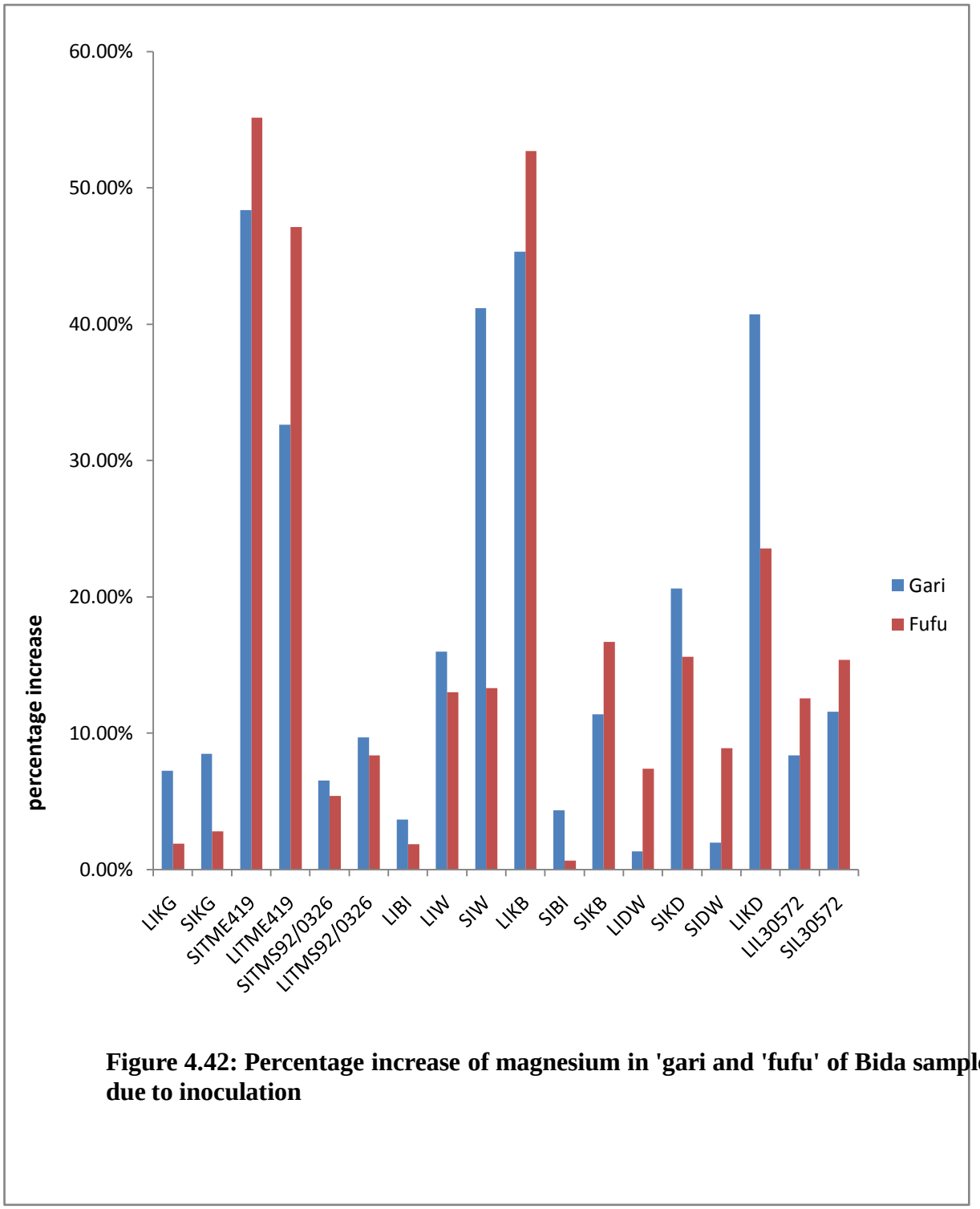


Figure 4.42: Percentage increase of magnesium in 'gari and 'fufu' of Bida samples due to inoculation

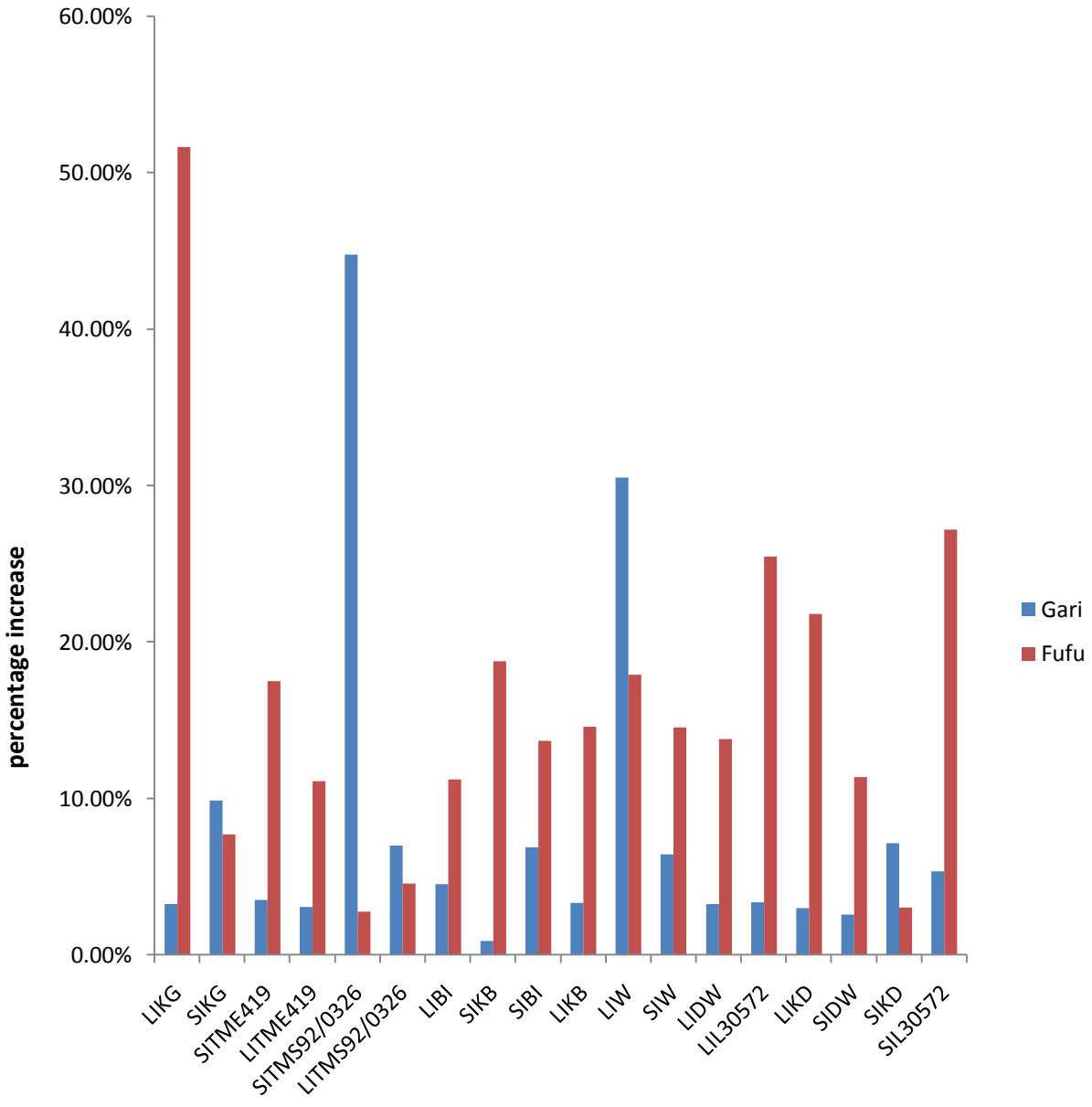


Figure 4.43: Percentage sodium increase in 'gari and 'fufu' of Suleja samples due to inoculation

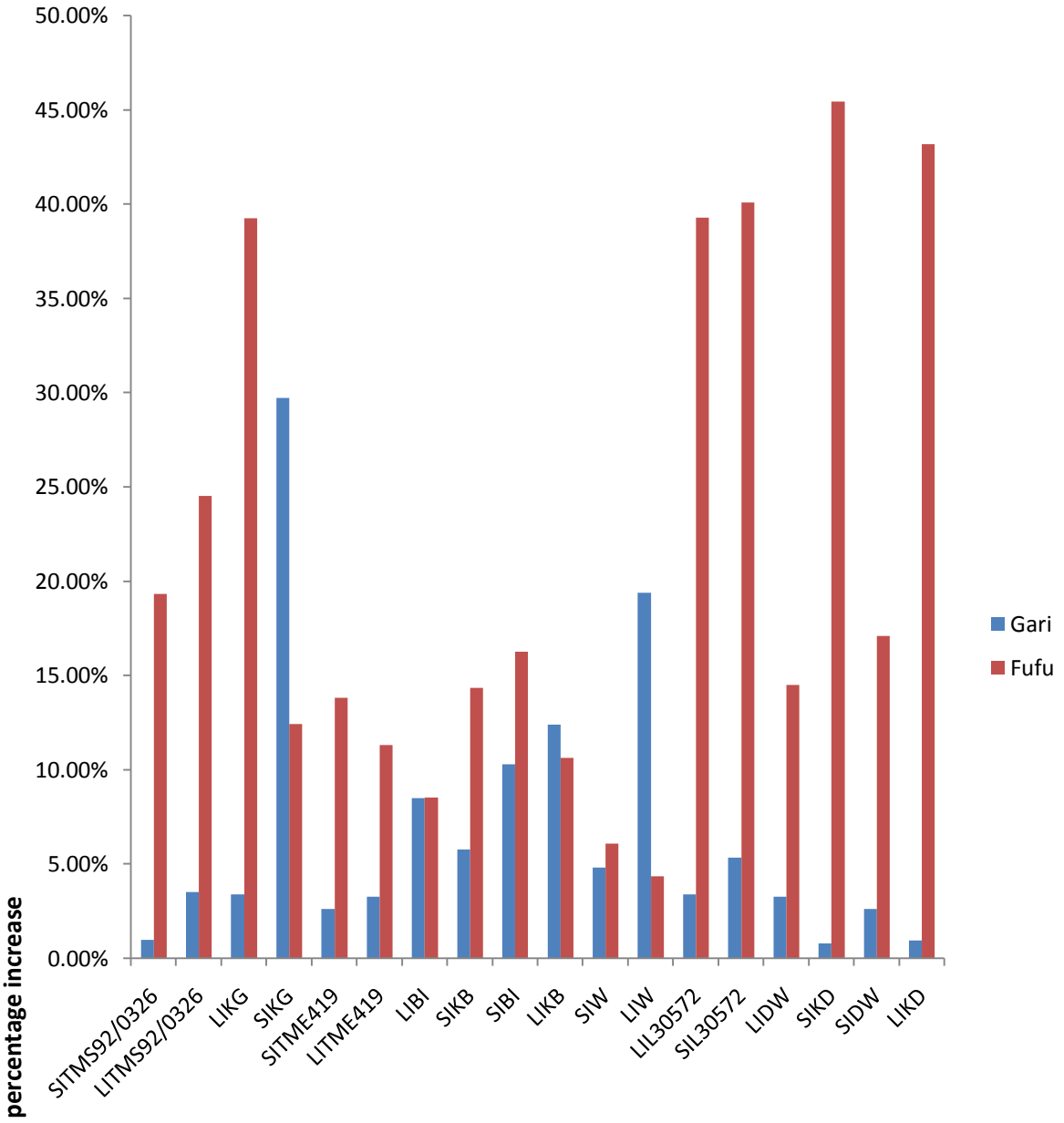


Figure 4.44: Percentage increase of sodium in 'gari and 'fufu' of Kontgora samples due to inoculation

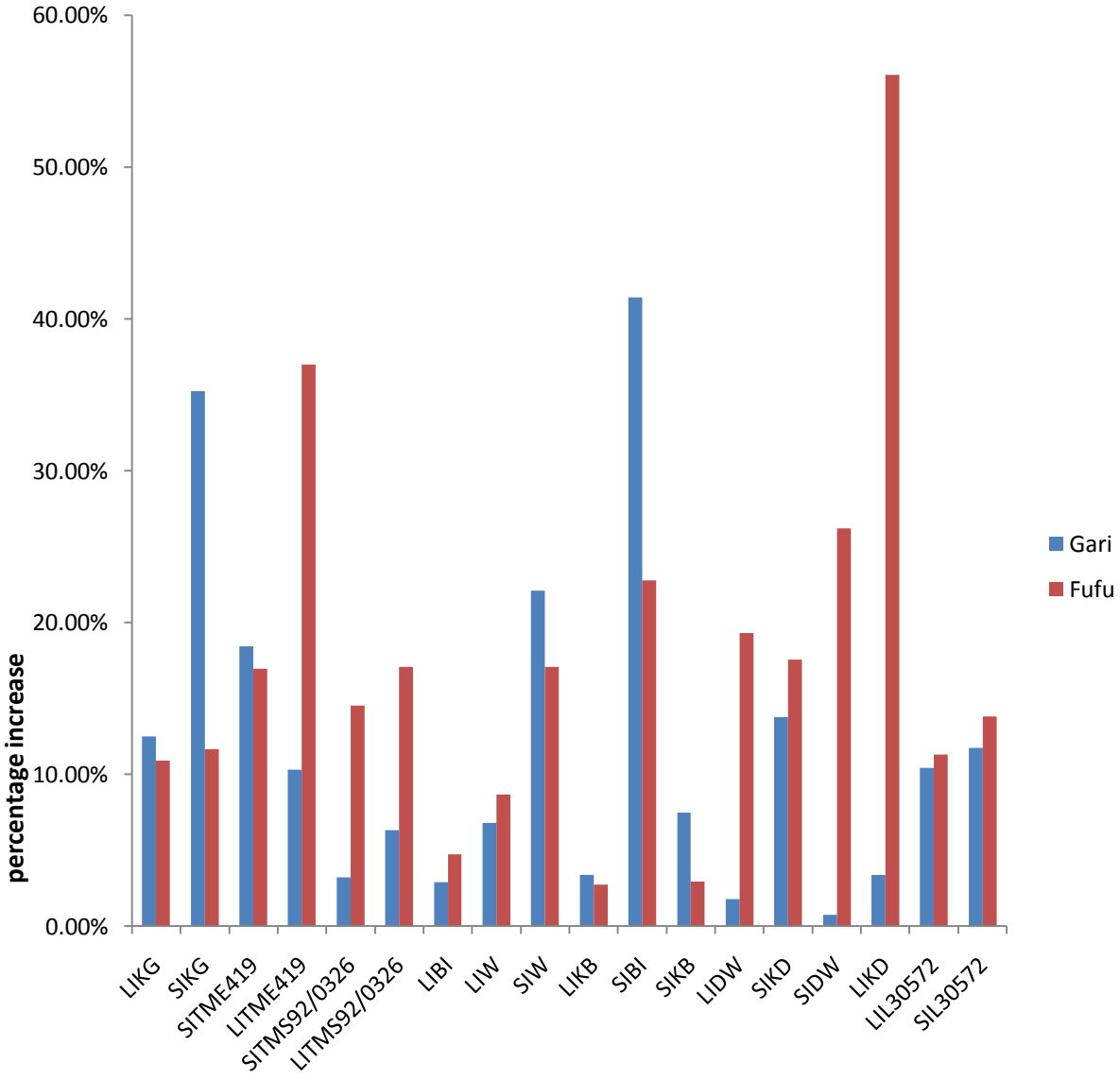


Figure 4.45: Percentage increase of sodium in 'gari and 'fufu' of Bida samples due to inoculation

Figure 4.46 contains the result of the level of potassium percentage increase in 'fufu' and 'gari' products microbially fermented of Suleja cassava product samples. The highest increase in percentage was recorded in *S. cerevisae*-fermented 'fufu'obtained from 'kpace bokun' variety (47.13%) and lowest in 'fufu' produced from TMS92/0326 variety inoculated with *L. bulgaricus* (0.51%).

Figure 4.47 contains the result of the level of potassium percentage increase in 'fufu' and 'gari' products microbial fermented of Kontagora cassava product samples. Percentage increase was found to be highest in 'gari' products of 'Baba Iya' and 'Dan Warri varieties'obtained through *S. cerevisae* fermentation (54.50% and 54.53% respectively), and the lowest value for 'fufu' however, was found in the 'fufu' produced from TMS92/0326 variety inoculated with *L. bulgaricus* (0.51%).

The percentage increase of potassium in 'fufu' and 'gari products of Bida samples are presented in Figure 4.48. A highest value of 39.45% increase in potassium was recorded in 'gari' produced from TME419 through *S. cerevisae* fermentation and a lowest value of 0.94% was found in 'fufu' made from TMS92/0326 through *S. cerevisae* inoculation.

The result of increase in percentage of calcium for microbially fermented cassava products obtained from Suleja sampling is are presented in Figure 4.49. These values of cacium ranged from 1.16% for 'fufu' made from L30572 and treated with *L. bulgaricus* to 17.21% for 'fufu' produced from 'Kpace Bokun' through *S. cerevisae* fermentation.

The result of increase of percentage in calcium for microbially fermented cassava products obtained from Kontagora sampling area are presented in Figure 4.50 These values ranged from 3.13% for 'gari' made from 'Karimugi' fermented with *S. cerevisae* and 21.67% for 'fufu' produced from 'Kpace Bokun' through *S. cerevisae* fermentation.

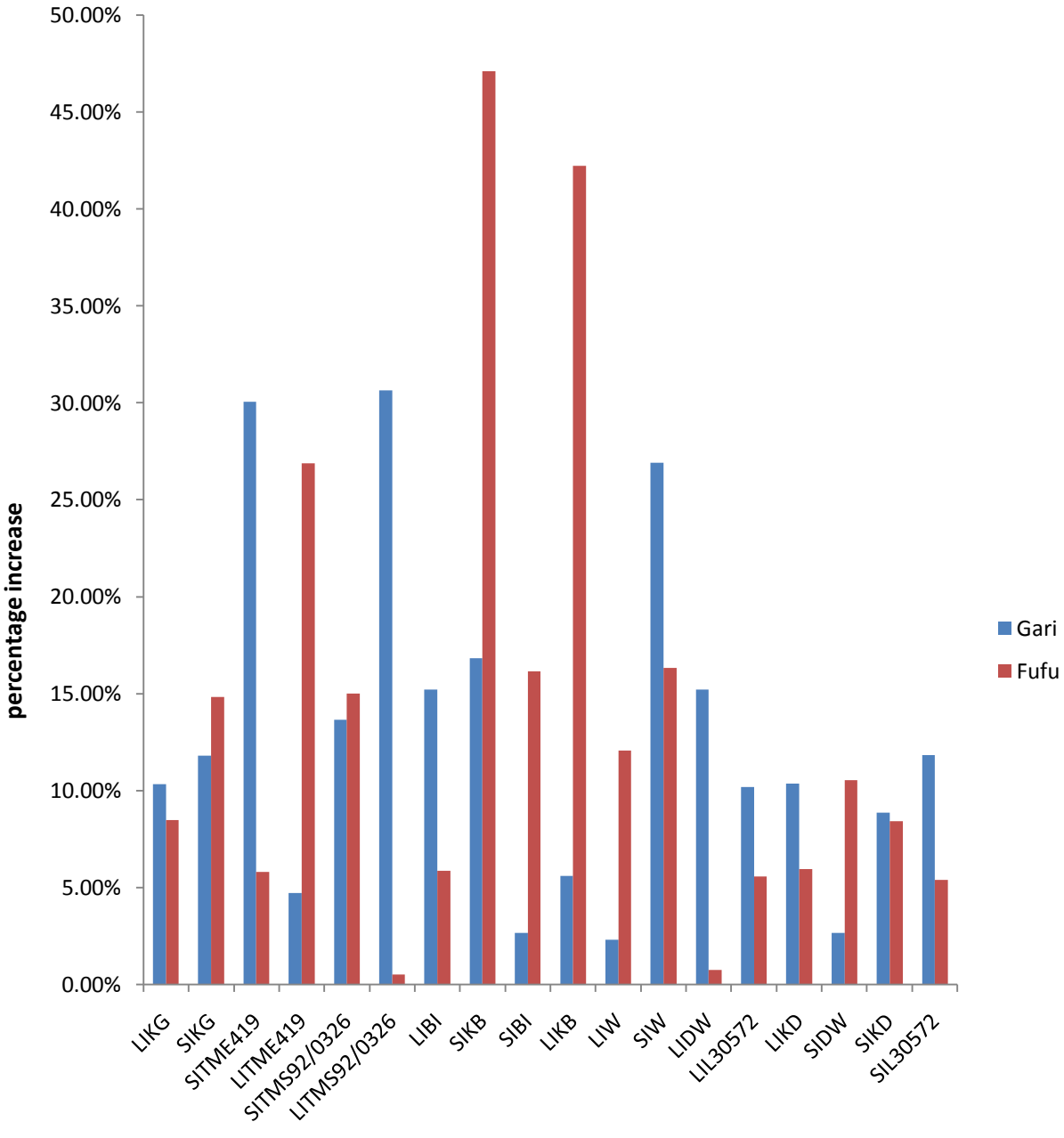


Figure 4.46: Percentage increase of potssium in 'gari and 'fufu' of Suleja samples due to inoculation

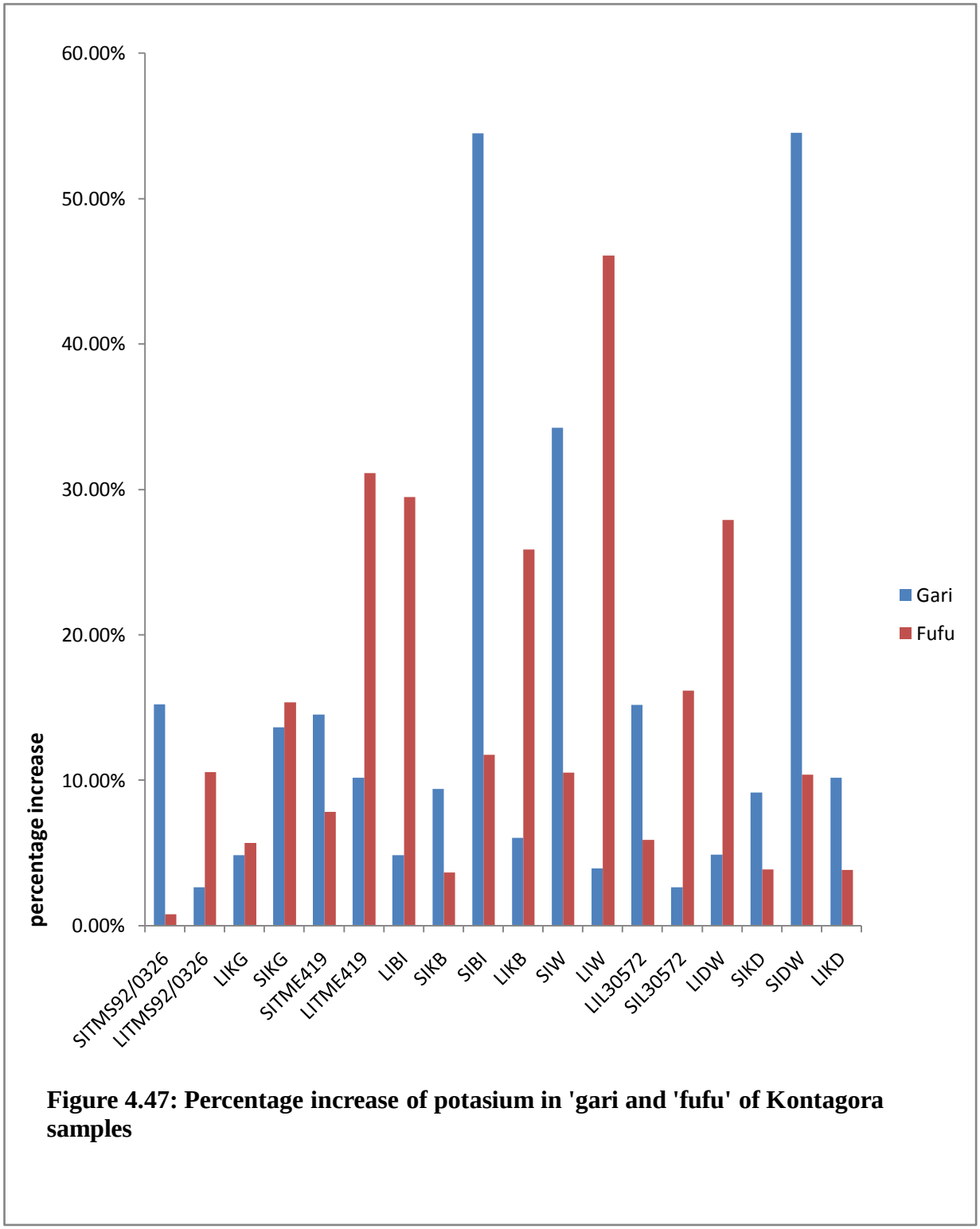


Figure 4.47: Percentage increase of potasium in 'gari and 'fufu' of Kontagora samples

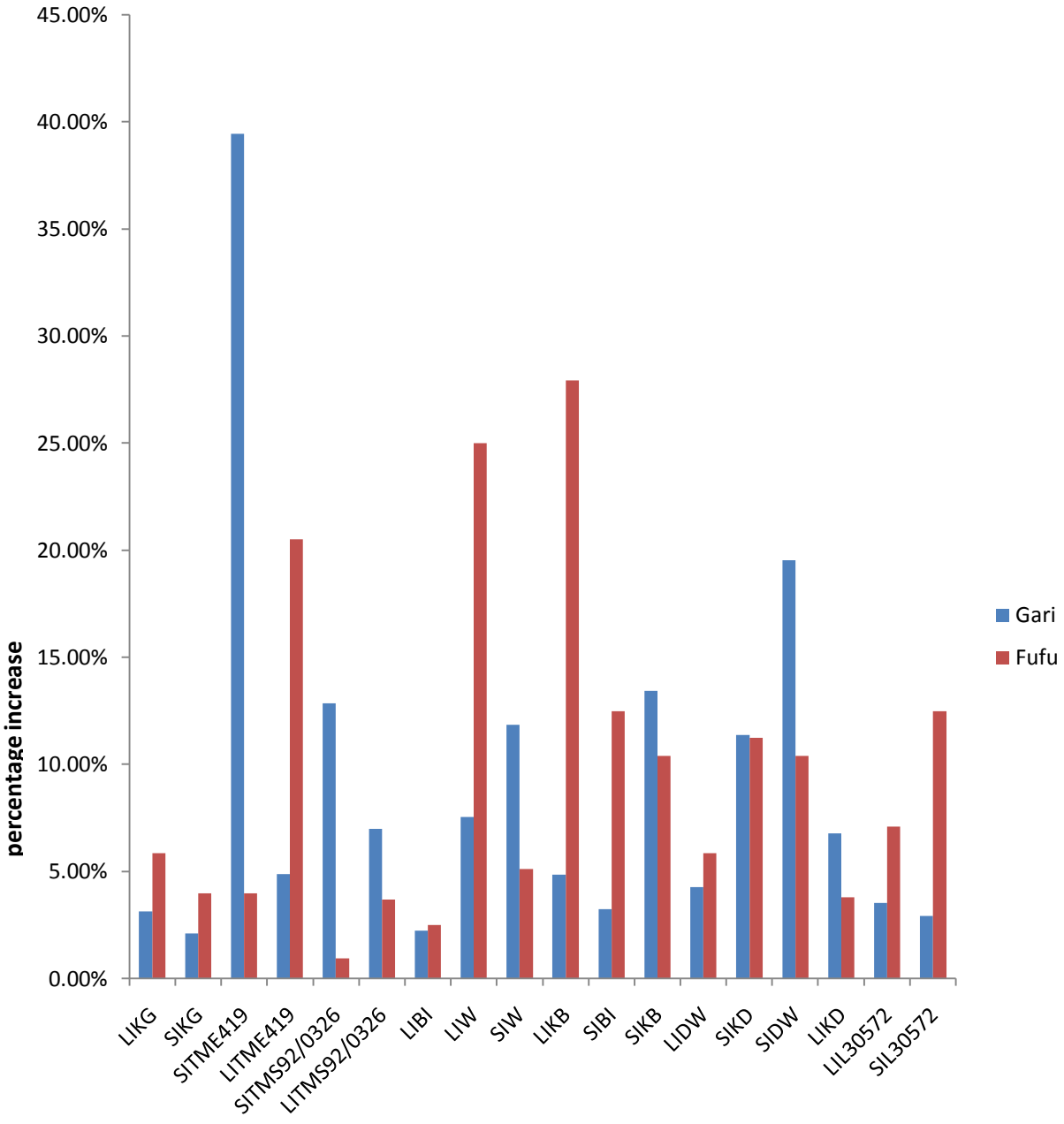


Figure 4.48: Percentage increase of potassium in 'gari and 'fufu' of Bida samples due to inoculation

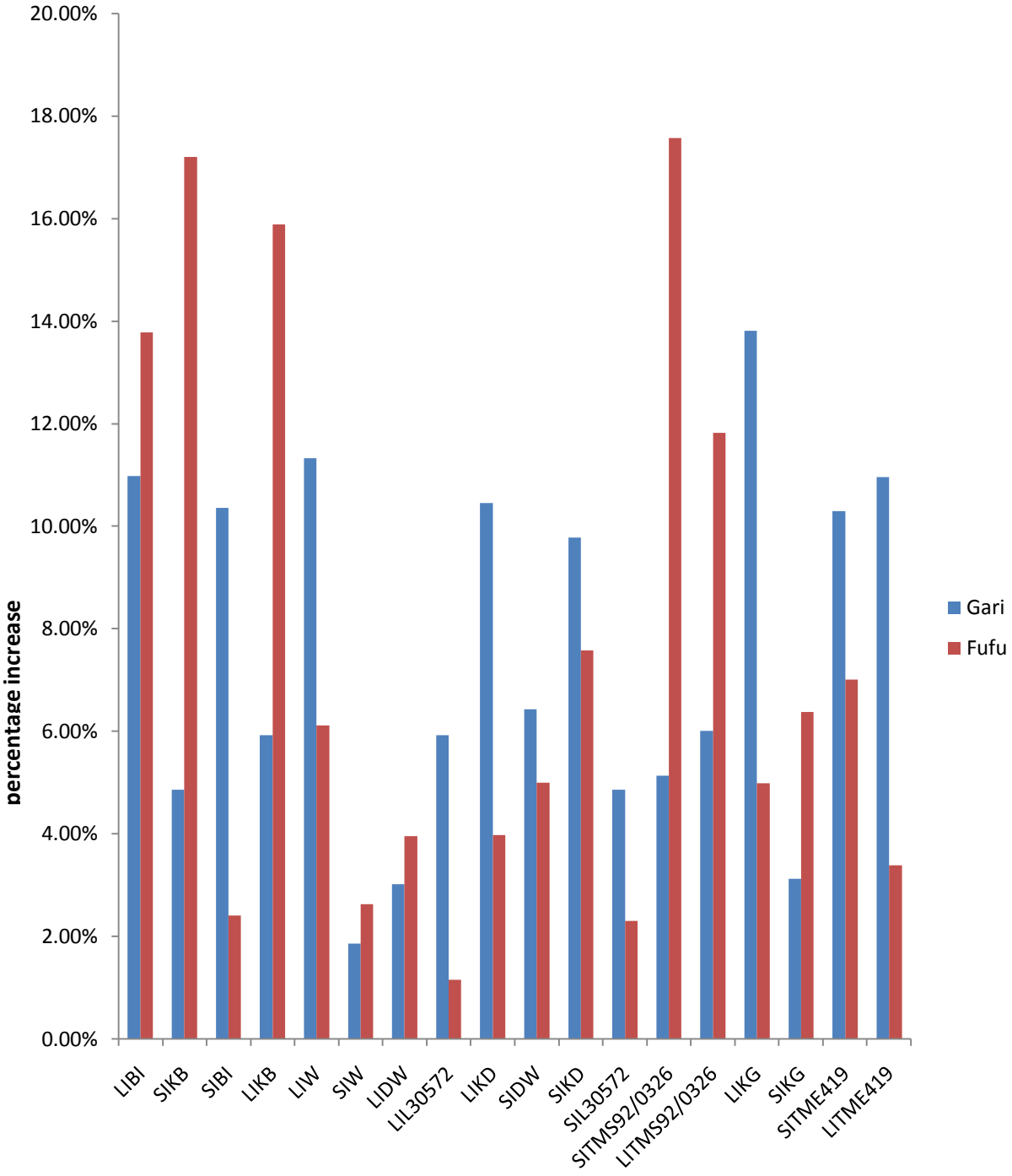


Figure 4.49: Percentage increase of calcium in 'gari and 'fufu' of Suleja samples due to inoculation

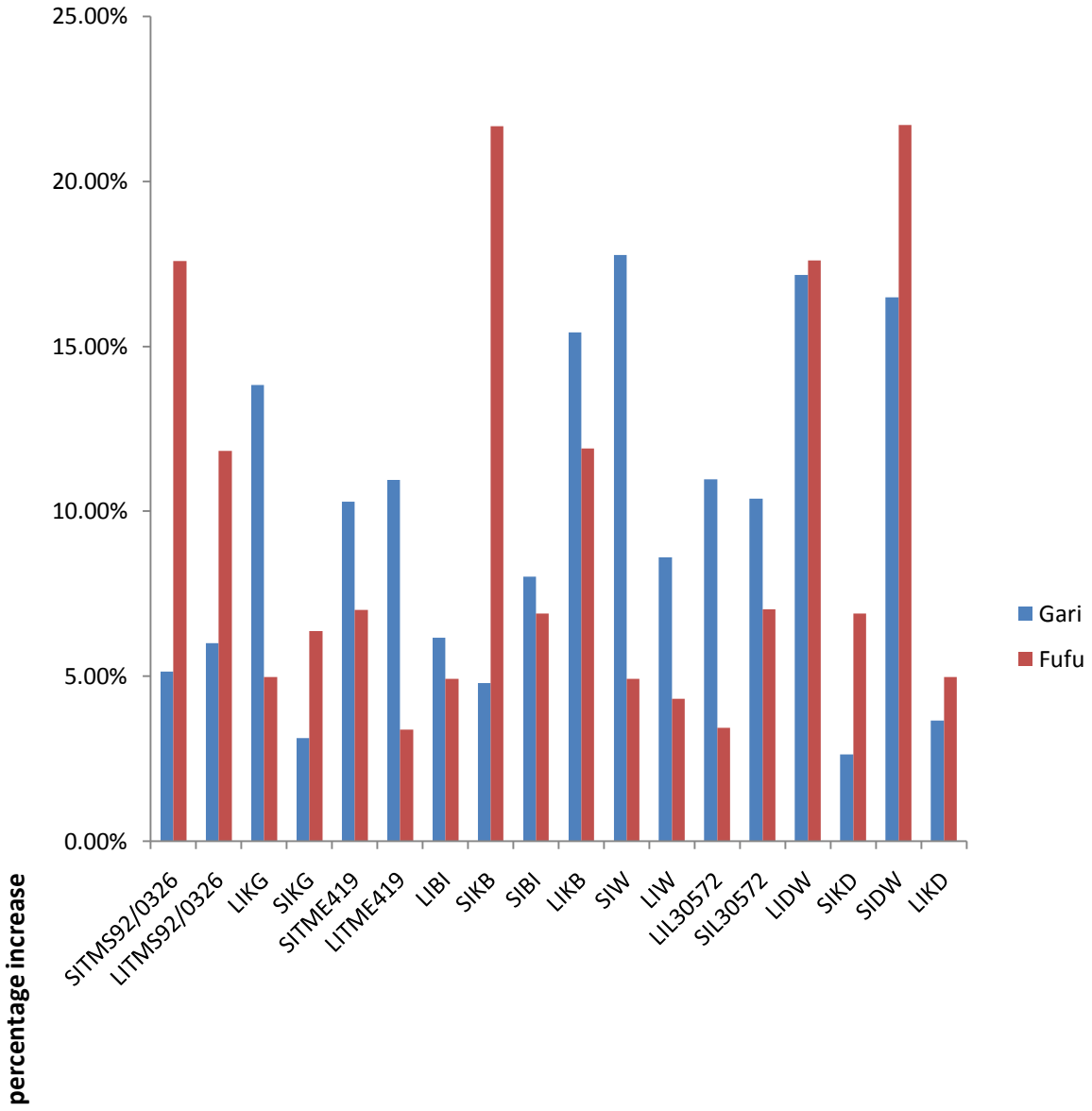


Figure 4.50: Percentage increase of calcium in 'gari and 'fufu' of Kontagora samples due to inoculation

The result of increase of percentage in calcium for microbially fermented cassava products obtained from Kontagora sampling area are presented in Figure 4.50 These values ranged from 3.13% for 'gari' made from 'Karimugi' fermented with *S. cerevisae* and 21.67% for 'fufu' produced from 'Kpace Bokun' through *S. cerevisae* fermentation.

Figure 4.51 contains the results of the level of calcium percentage increase in 'fufu' and 'gari' products microbially fermented of Bida cassava samples. The values of calcium ranged btween 0.50% and (19.41%) in *S. cerevisae*-inoculated 'gari' obatained from 'Karimugi' and *L. bulgaricus*-inoculated 'fufu' produced from 'Kpace Bokun' respectively.

Levels of increase in percentage of iron in 'fufu' and 'gari; products microbially produced from Suleja cassava samples are prensented in Figure 4.52. The highest percentage increase was observed in 'fufu' produced from'Kpace Bokun' through *S. cerevisae* fermentation (47.48%) and 'fufu' from TME419 inoculated with *L. bulgaricus (*44.12%), while the lowest values was recorded in 'Karimugi's 'gari' produced through *S. cerevisae* fermentation (1.45%) and 'fufu' manufactured from 'Kpace Dzuru' through *L. bulgaricus* fermentation (1.28%).

Result of levels of increase in percentage of iron of 'fufu' and 'gari; products microbially produced from Kontagora cassava samples is presented in Figure 4.53. It was observed from the results that there was no significant difference among the values obtained for the products from L30572, 'Dam Warri', and 'Kpace Dzuru' varieties of the two fermentations.

Results of increase in percentage of iron in 'fufu' and 'gari; products microbial produced from Bida cassava samples are presented in Figure 4.54. The level of iron ranged from 0.58% to 46.82% in *S. cerevisae*-fermented produced from 'Baba Iya' and *S. cerevisae*-inoculated 'fufu' obtained from L30572 respectively.

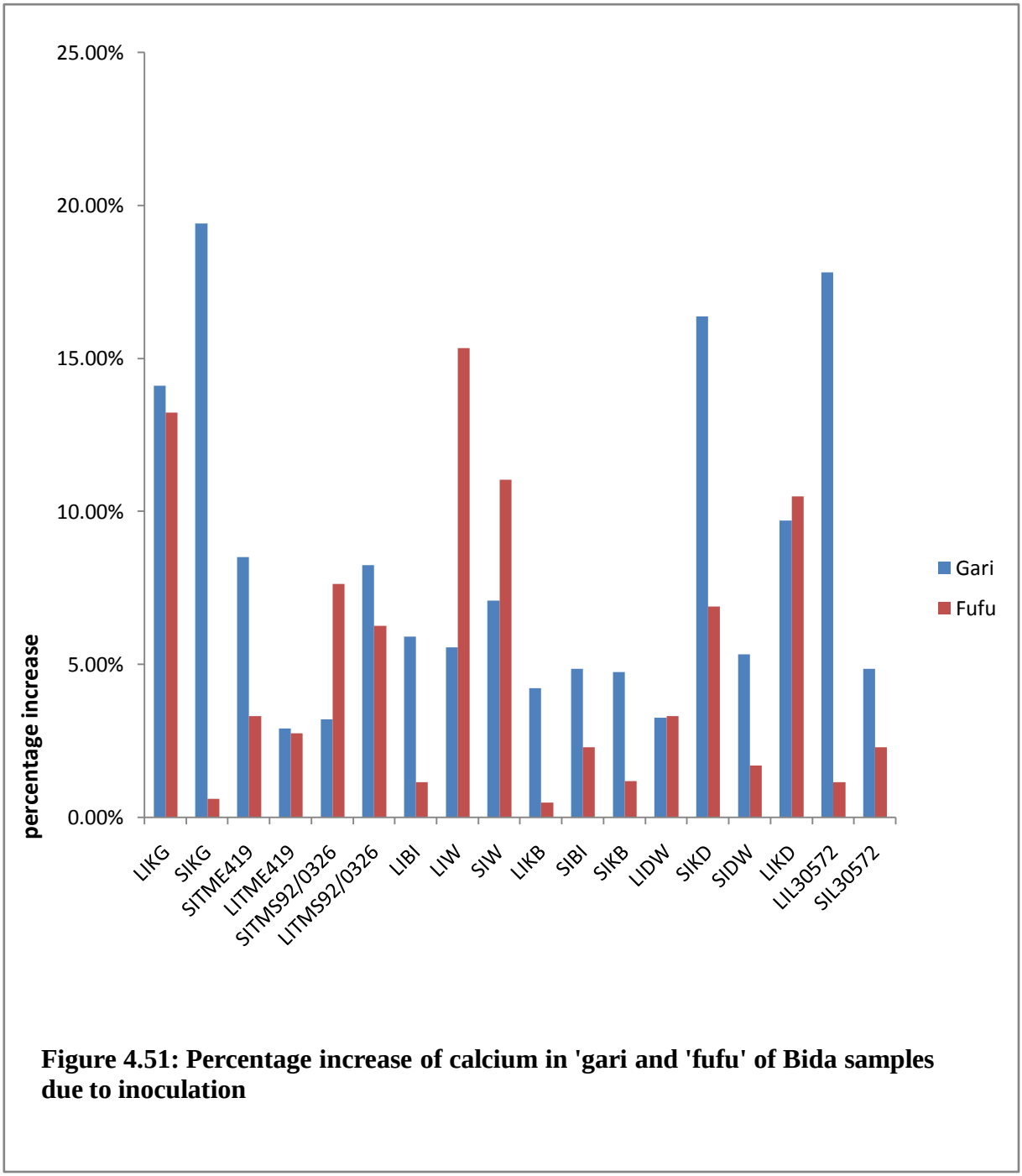


Figure 4.51: Percentage increase of calcium in 'gari and 'fufu' of Bida samples due to inoculation

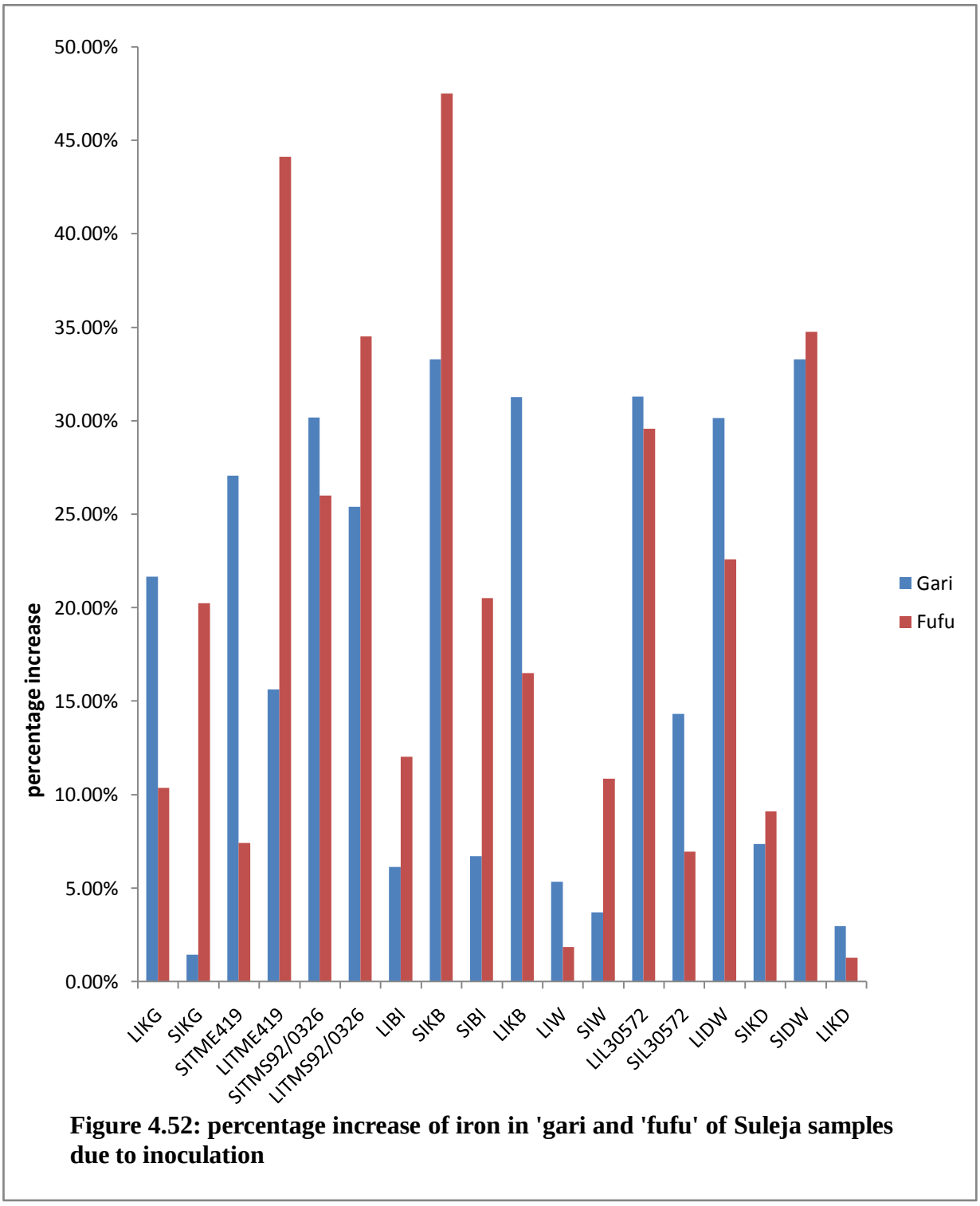


Figure 4.52: percentage increase of iron in 'gari and 'fufu' of Suleja samples due to inoculation

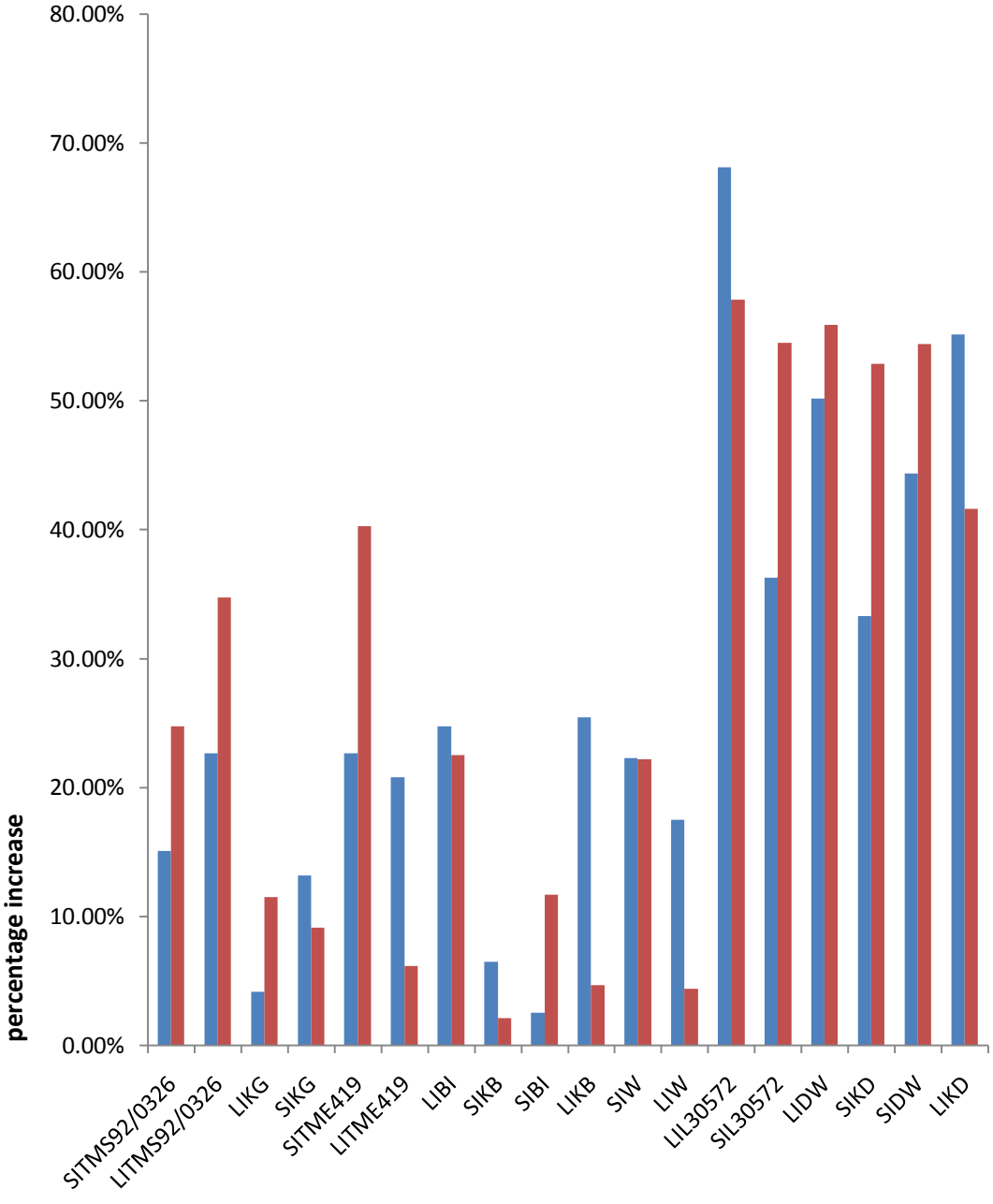


Figure 4.53: Percentage increase of iron in 'gari and 'fufu' of Kontagora samples due to inoculation

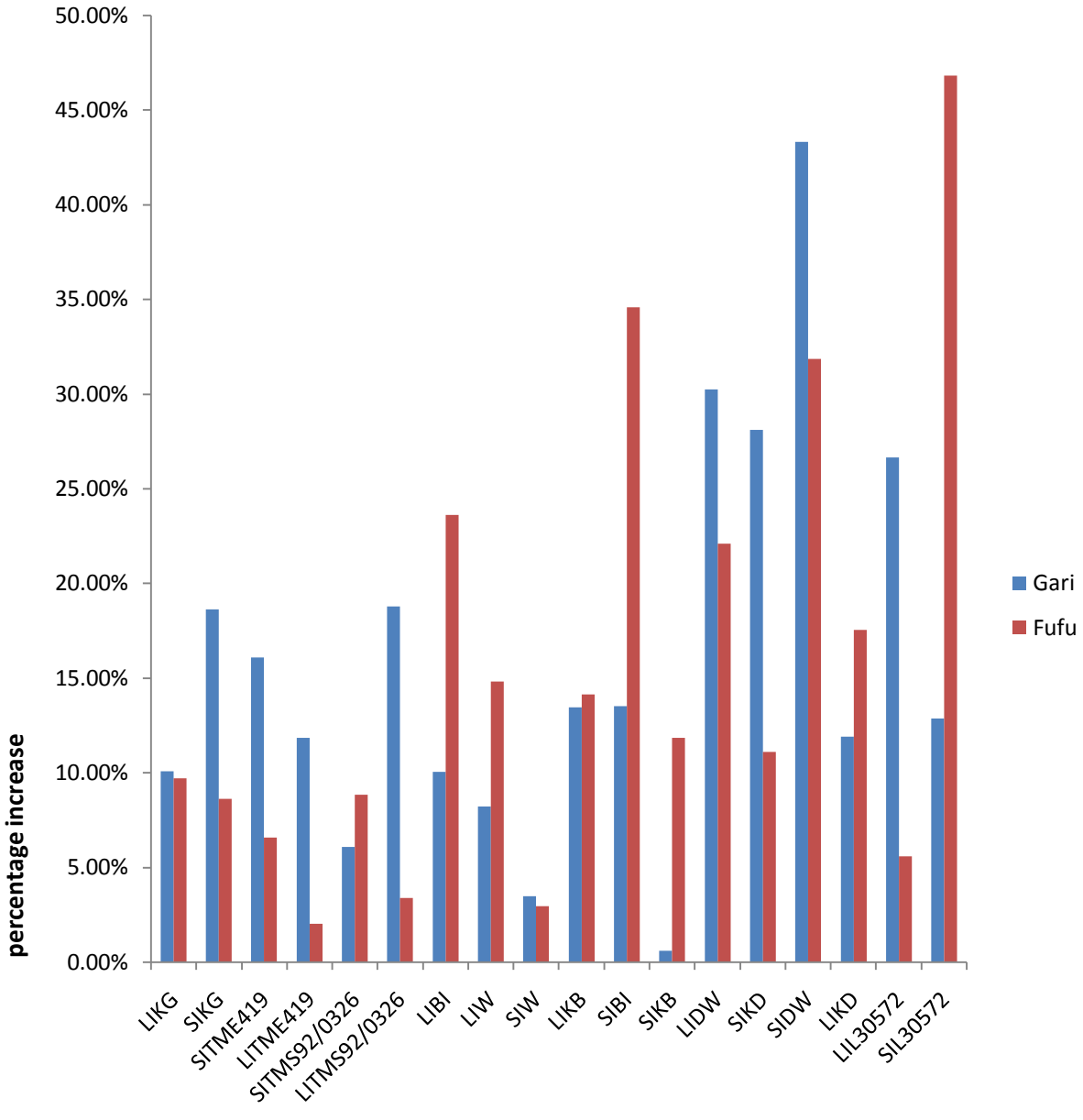


Figure 4.54: Percentage increase of iron in 'gari and 'fufu' of Bida samples due to inoculation

Figure 4.55 represents the result of level of increase in percentage of phosphorus in cassava-based products - ‘fufu’and ‘gari’- produced from Suleja cassava samples through microbial fermentation. There were significant increase in ‘fufu’ (25.98%) from ‘Karimugi’ cultivar through *L. bulgaricus* fermentation, ‘fufu’ (23.99%) from ‘Karimugi’ of *S. cerevisae* fermentation and ‘fufu’ products (21.33% and 25.98%) from ‘Kpace Dzuru through *L. bulgaricus* and *S. cerevisae* fermentations respectively compared to the uninoculated couterparts ($P < 0.05$). Cultivars of L30572 and ‘Baba iya’ were observed to be very low in phosphorus content in both ‘gari’ and ‘fufu’ products.

Figure 4.56 represent the results of level of increase in percentage of phosphorus in cassava-based products -‘fufu’and ‘gari’- produced from Kontagora cassava samples through microbial fermentation. There were significant increase in in the phosphorus in ‘gari’ (21.56%) made from ‘Karimugi’ cultivar through *S. crevisae* fermentation, ‘gari’ (26.88%) produced from TMS92/0326, ‘fufu’ (25.98%) from TME419 and ‘fufu’ (25.98%) obtained from‘baba iya’ through the action of *L. bulgaricus.*

Figure 4.57 presents the result of percentage increase of phosphorus in the cassava-based products - ‘fufu’and ‘gari’- produced from Bida cassava samples through microbial fermentation. There was a significant increase in the amount of phosphorus for ‘fufu’ (49.32%) from ‘Kpace Bokun’ cultivar through *S. cerevisae* fermentation compared to the rest of the products.

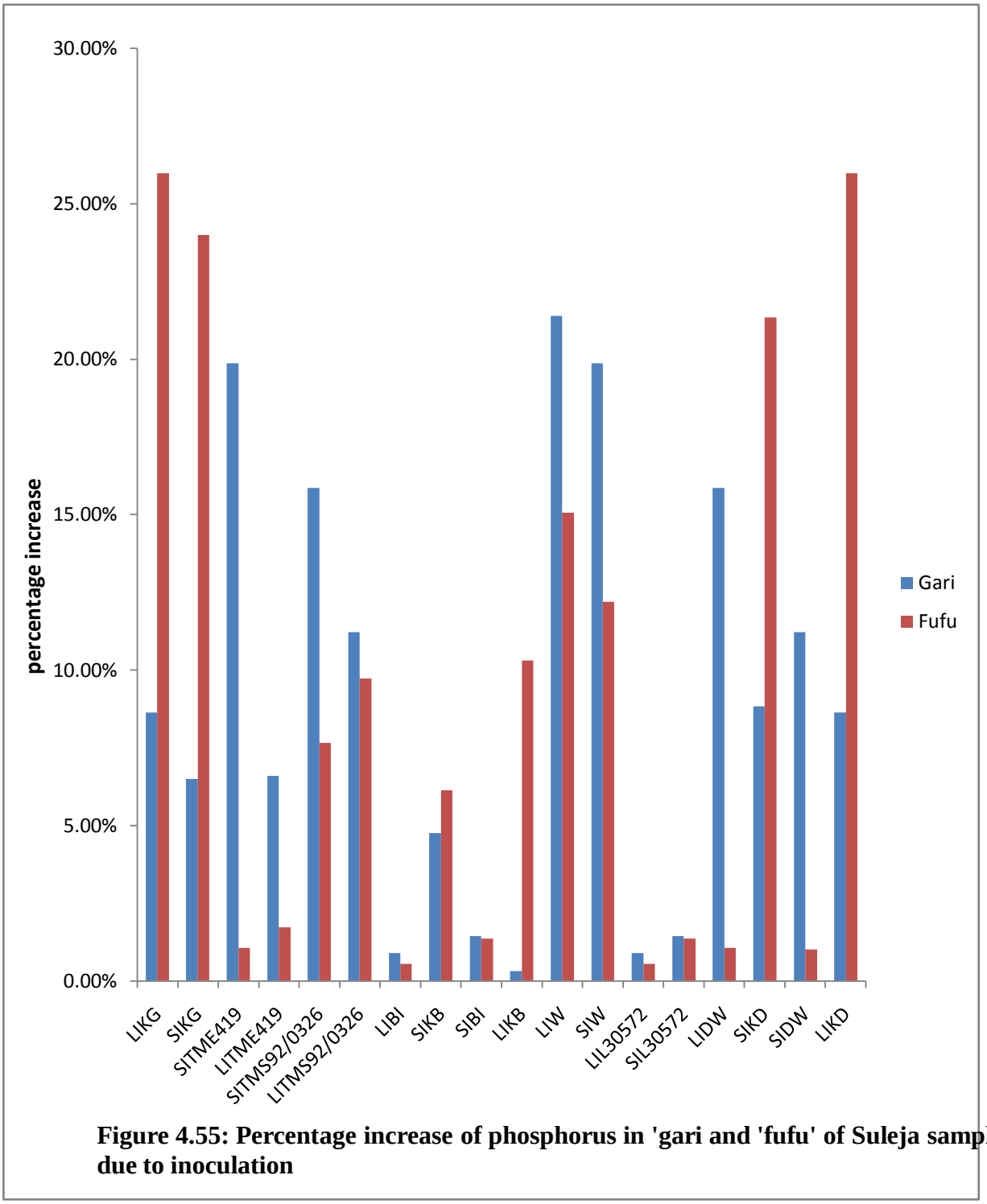


Figure 4.55: Percentage increase of phosphorus in 'gari and 'fufu' of Suleja samples due to inoculation

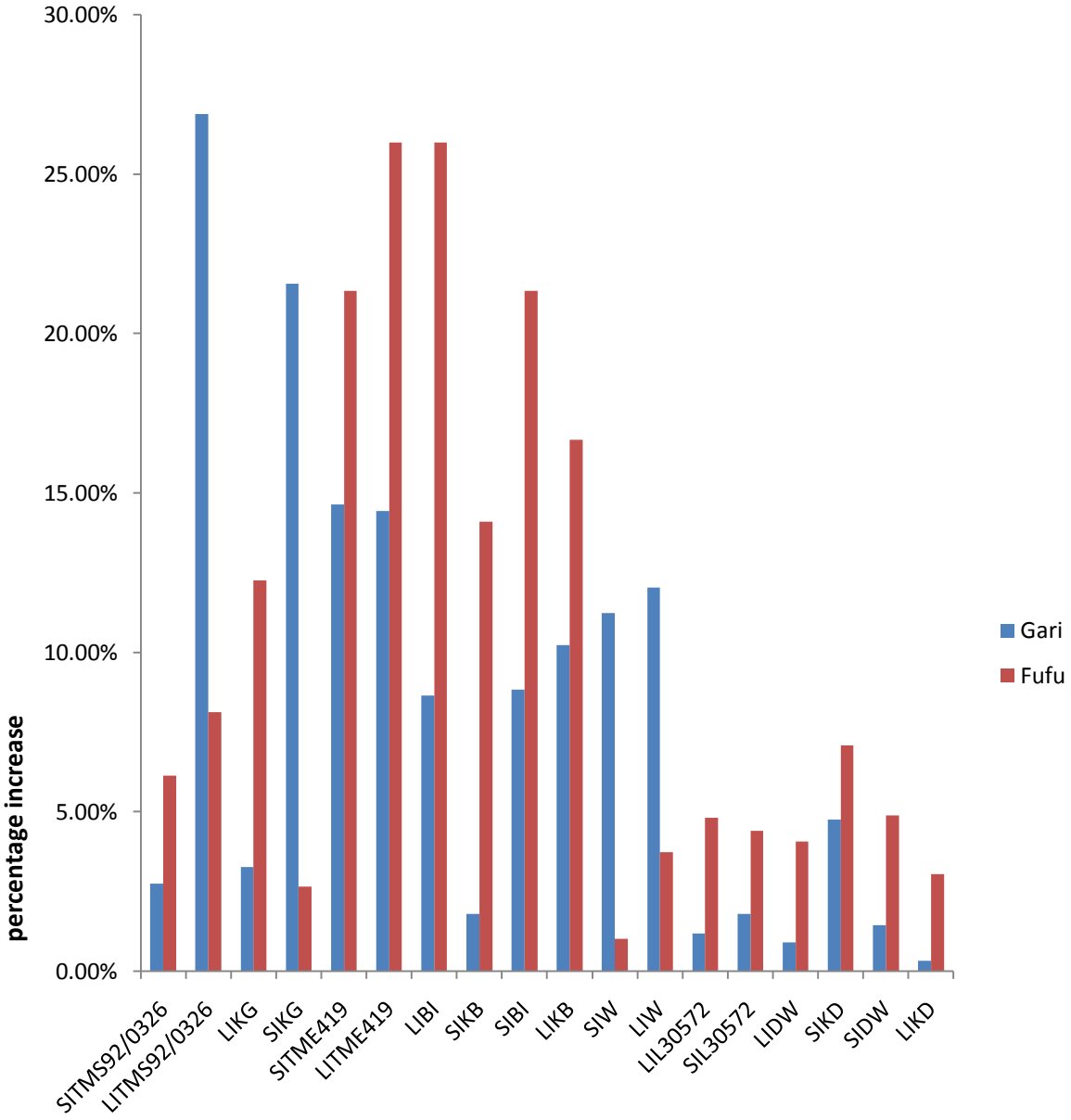


Figure 4.56: Percentage increase of phosphorus in 'gari and 'fufu' of Kontagora samples due to inoculation

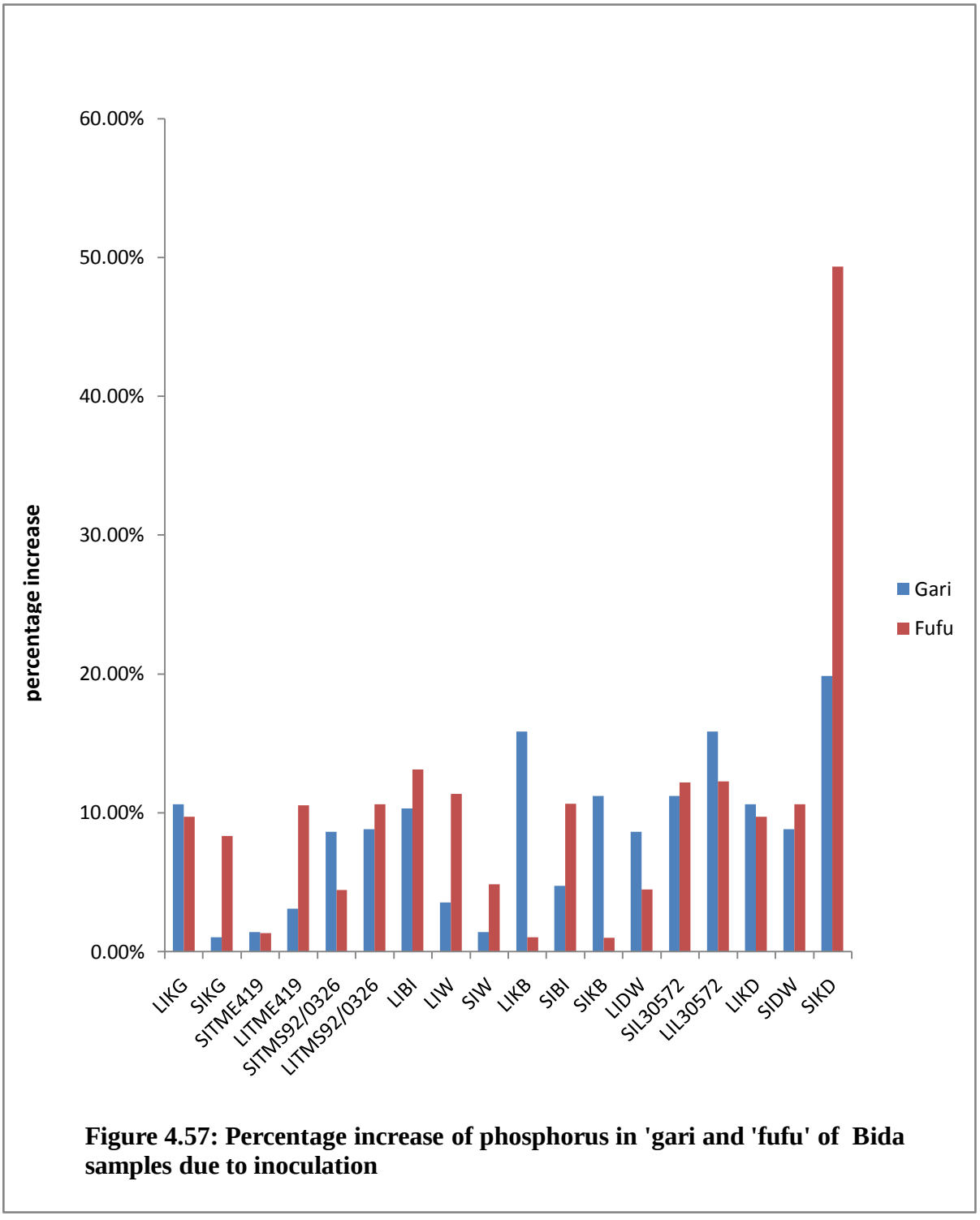


Figure 4.57: Percentage increase of phosphorus in 'gari and 'fufu' of Bida samples due to inoculation

4.4 The results of Physico-chemical Compositions of Soil Samples from the Three Sampling Areas

The results of soil composition of the three areas where cassava samples were planted are presented in Tables 4.1, 4.2 and 4.3. Table 4.1 shows the Physico-chemical parameters of the soils from Kotagora zone which covered Wushshi, Bunigi, Kawo and Maito sites. Table 4.2 indicates the Physico-chemical parameters of the soils from Suleja area. Kpasson ,Gwam, Jita and Shipagbe are sites covered within the Suleja area.

Table 4.3 depicts the Physico-chemical parameters of the soils from Bida covering Batavovogi, Masaga, Kuchita and Kupafu sampling sites. The parameters considered in in each case included copper, iron, magnesium, sodium, potssium, texture (silt, sand and clay) organic carbon, organic matter and pH. The pH values obtained for all the soil samples were not significantly different ($P > 0.05$), values ranged from 6.00 ± 0.15 to 6.30 ± 0.08 (Tables 4.1, 4.2 and 4.3). This indicated that the soil samples are fairly acidic.

Furthermore there were no clear trends in the level of silt and clay contents for both the topsoil and subsoil samples of the sampling points. The values for sand, silt and clay contents ranged from $70.42 \pm 1.31\%$ to $81.57 \pm 0.82\%$, $5.23 \pm 0.32\%$ to $10.25 \pm 0.25\%$ and $11.25 \pm 0.21\%$ to $22.23 \pm 0.43\%$ respctively (Table 4.1, 4.2 and 4.3). Of the elements (iron, magnesium, sodium, potassium, calcium, copper and phosphorus) determined, those that were of low compositions were the copper and available phosphorus.

Table 4.1: Physico-chemical parameters of the soils from Kotagora zone

Sample	Parameters													
	Fe (mg/kg)	Cu (mg/kg)	Sand (%)	Silt (%)	Clay (%)	TC	pH	OC (mg/kg)	OM (mg/kg)	Na (mg/kg)	K (mg/kg)	Mg (mg/kg)	Ca (mg/kg)	AP (mg/kg)
KWOTS	1370.67±11.54h	45.36±0.97c	79.27±0.07e	9.24±0.33g	11.30±0.07a	SL	6.20±0.11a	1666.68±5.78e	2866.65±5.54e	176.71±1.83d	1918.47±4.48l	1120.34±8.21de	2080.65±8.48hi	674.55±4.81gh
KWOSS	1674.72±5.34j	68.33±0.89de	74.53±0.81ab	8.21±0.71e	17.37±0.67fg	SL	6.10±0.01a	2496.59±5.81g	4299.98±4.54g	467.75±3.07i	2058.85±5.58m	800.57±7.87ab	1680.08±9.48e	581.53±3.38b
WSSTS	1440.17±3.31h	60.33±1.23d	77.59±0.88d	9.19±0.43g	13.20±0.11bc	SL	6.30±0.08a	1666.63±6.18e	2866.67±7.07e	83.16±0.32ab	2246.02±2.28p	1600.56±9.68g	2160.45±6.68j	587.77±7.89b
WSSSS	2484.37±2.31m	45.13±0.65c	81.57±0.82e	6.26±0.09d	11.25±0.21a	LS	6.00±0.41a	1749.92±4.28e	3009.98±8.34e	176.75±2.23d	1216.59±9.89f	1440.53±5.58f	1760.34±8.78fg	664.45±2.21fg
MATTS	894.57±2.30e	30.19±0.88b	70.42±1.31a	7.23±0.31e	22.23±0.43j	SL	6.00±0.23a	1749.93±8.10e	3009.28±9.32e	93.56±4.48ab	1965.26±5.51l	710.23±6.68a	1860.67±6.86gh	629.49±3.38e
MATSS	2052.21±9.31l	387.29±3.23i	73.25±0.59ab	10.25±0.25h	16.30±0.61cd	SL	6.10±0.31a	2166.58±8.56f	3726.65±5.58f	519.75±3.84j	421.13±3.13b	1120.22±7.84de	1600.40±8.88e	716.43±3.82l
BNGSS	1902.54±7.39k	105.33±2.43g	81.37±0.52e	5.23±0.32c	13.17±0.90bc	LS	6.00±0.41a	1249.99±3.84cd	2149.94±7.78bc	124.74±5.86cd	2292.80±8.46p	800.09±6.85ab	1040.05±7.86a	654.45±4.45f
BNGTS	1482.67±5.78hi	60.38±0.27d	74.59±0.32ab	10.25±0.15h	15.23±0.12cd	SL	6.00±0.15a	2666.65±6.65g	4586.64±6.87g	218.25±7.88ef	1778.096±1.81j	1840.11±10.45h	960.68±6.67a	734.64±4.45m

KEY:

AP = Available phosphorus, TC = Textural class, OC = Organic carbon, OM = Organic matter, SL = Sandy-loamy, LS = Loamy-sandy, KWOTS = Kawo Topsoil, KWOSS = Kawo Subsoil, WSSSS = Wushishi Subsoil, WSSTS = Wushishi Top soil, MATTS = Maito Topsoil, MATSS = Maito Subsoil, BNGSS = Bunigi Subsoil, BNGTS = Bunigi Topsoil

Means with the same superscript within a column are not significantly different ($p > 0.05$)

Table 4.2: Physico-chemical parameters of the soils from Suleja zone

Sample	Parameters													
	Fe (mg/kg)	Cu (mg/kg)	Sand (%)	Silt (%)	Clay (%)	TC	pH	OC (mg/kg)	OM (mg/kg)	Na (mg/kg)	K(mg/kg)	Mg (mg/kg)	Ca (mg/kg)	AP (mg/kg)
SPGSS	2046.43±6.00^{l}	75.12±1.77^{e}	77.52±0.58^{d}	11.22±0.57^{i}	11.28±0.58^{a}	SL	6.00±0.58^{a}	1749.92±4.86^{e}	3009.98±7.66^{e}	311.85±5.86^{gh}	748.72±6.71^{d}	1120.09±9.81^{de}	1440.08±9.83^{d}	636.00±2.85^{e}
SPGTS	1572.34±2.00^{ij}	75.34±2.01^{e}	71.15±1.12^{a}	8.18±0.34^{ef}	20.27±0.45^{i}	SL	6.70±0.30^{a}	2666.65±3.78^{g}	4586.64±9.82^{g}	176.71±8.65^{d}	2292.81±8.01^{p}	1440.45±6.78^{f}	1600.82±8.28^{e}	661.53±3.83^{f}
KSOSS	4404.23±4.00^{p}	210.43±4.32^{h}	79.24±0.52^{e}	5.24±0.12^{c}	15.12±0.11^{cd}	SL	6.07±0.25^{a}	999.93±5.68^{ab}	1719.99±6.11^{bc}	207.90±6.68^{e}	2058.85±5.19^{m}	800.09±9.08^{ab}	2000.54±5.58^{hi}	597.08±8.68^{c}
KSOTS	624.32±4.00^{cd}	30.31±1.15^{b}	83.42±1.81^{g}	3.21±0.06^{a}	13.23±0.21^{bc}	LS	6.00±0.57^{a}	833.63±1.80^{a}	1433.32±4.51^{a}	20.79±0.89^{a}	795.46±4.58^{d}	960.56±8.18^{cd}	1440.07±7.87^{d}	638.57±7.77^{e}
GWMSS	2874.43±2.30^{n}	45.27±0.45^{c}	76.67±1.18^{c}	8.32±0.42^{ef}	15.32±0.42^{cd}	SL	6.13±0.06^{a}	1249.95±1.81^{cd}	2149.09±5.53^{bc}	176.44±1.72^{d}	2433.18±2.48^{q}	2080.45±5.58^{i}	1360.49±7.78^{cd}	685.45±5.88^{hi}
GWMTS	546.12±5.67^{c}	60.39±2.02^{d}	81.22±0.64^{e}	8.79±0.41^{g}	11.17±0.90^{a}	LS	6.00±0.10^{a}	1166.62±6.87^{bc}	2006.65±2.72^{bc}	103.48±1.13^{cd}	187.17±1.08^{a}	1040.56±4.32^{cd}	1200.56±6.68^{b}	693.38±3.82^{jk}
JTATS	204.67±2.31^{a}	30.67±1.21^{b}	79.34±1.13^{e}	11.18±0.13^{i}	18.21±0.22^{gh}	SL	6.00±0.07^{a}	2499.96±6.81^{g}	4299.18±8.90^{g}	239.42±5.82^{g}	2058.85±8.74^{m}	1200.56±6.68^{ef}	1600.34±5.48^{e}	600.89±5.85^{c}
JTASS	3474.86±5.77^{o}	75.25±1.25^{e}	83.58±1.81^{g}	5.38±0.58^{c}	11.18±0.08^{a}	LS	6.10±0.20^{a}	2749.90±4.91^{g}	4729.98±6.66^{g}	311.85±1.05^{gh}	1497.34±4.83^{h}	1440.45±5.58^{f}	1360.05±9.08^{cd}	698.34±4.82^{jk}

KEY:

AP = Available phosphorus, TC = Textural class, OC = Organic carbon, OM = Organic matter, SL = Sandy loam, LS = Loamy sand , SPGSS = Shipagbe Subsoil, SPGTS = Shipagbe Topsoil, KSOSS = Kpasson Subsoil, KSOTS = Kpasson Topsoil, GWMSS = Gwam Subsoil, GWMTS = Gwam Topsoil, JTATS = Jita Topsoil, JTASS = Jita Subsoil.

Means with the same superscript within a column are not significantly different ($p > 0.05$)

Table 4.3: Physico-chemical parameters of the soils from Bida zone

Sample	Parameters													
	Fe (mg/kg)	Cu (mg/kg)	Sand (%)	Silt (%)	Clay (%)	TC	pH	OC (mg/kg)	OM (mg/kg)	Na (mg/kg)	K (mg/kg)	Mg (mg/kg)	Ca (mg/kg)	AP (mg/kg)
MSGTS	402,21±2.00^{b}	15.23±0.57^{a}	79.72±0.56^{e}	8.28±0.28^{f}	12.20±0.31^{ab}	SL	6.00±0.56^{a}	1166.67±1.28^{bc}	2006.65±8.21^{bc}	41.58±1.00^{a}	1123.08±7.08^{e}	880.54±8.98^{bc}	2400.63±9.68^{k}	535.42±4.84^{a}
MSGSS	834.23±5.77^{e}	45.33±0.89^{c}	75.62±2.38^{c}	7.23±0.43^{e}	17.23±0.16^{fg}	SL	6.30±0.20^{a}	916.63±2.81^{ab}	1576.43±5.48^{ab}	83.22±1.03^{ab}	2667.14±8.90^{r}	800.23±3.32^{ab}	2080.34±8.58^{hi}	587.07±5.86^{b}
KPFSS	858.37±4.31^{e}	30.42±0.56^{b}	82.29±0.52^{f}	4.20±0.18^{b}	13.26±0.31^{bc}	LS	6.00±0.23^{a}	1499.09±9.81^{de}	2579.98±9.89^{de}	395.01±3.01^{h}	1637.72±8.46^{i}	800.78±8.98^{ab}	1440.78±9.91^{d}	623.34±2.31^{d}
KPFTS	1182.67±2.31^{g}	45.09±0.43^{c}	77.52±1.53^{d}	6.22±0.38^{d}	16.26±0.25^{cd}	SL	6.00±0.05^{a}	3166.64±8.88^{h}	5446.64±9.99^{h}	135.14±3.03^{cd}	2105.64±6.85^{n}	1200.47±7.68^{ef}	2400.42±9.48^{k}	767.55±5.58^{n}
KCTTS	366.17±4.13^{b}	60.03±1.23^{d}	72.25±1.21^{ab}	8.24±0.46^{f}	19.32±0.08^{hi}	SL	6.10±0.02^{a}	1666.65±6.58^{e}	2866.62±5.98^{e}	72.77±0.89^{ab}	748.67±6.08^{d}	1120.30±8.38^{de}	1280.23±7.78^{bc}	690.98±5.85^{jk}
KCTSS	204.27±1.15^{a}	90.67±1.54^{f}	75.72±0.52^{c}	7.27±0.31^{e}	17.37±0.07^{fg}	SL	6.00±0.06^{a}	2249.91±8.09^{f}	3869.98±7.78^{f}	124.74±5.85^{cd}	1871.68±5.56^{k}	800.21±6.85^{ab}	2000.23±9.89^{hi}	680.58±4.85^{hi}
BTVTS	690.72±5.43^{d}	60.43±1.68^{d}	78.53±0.45^{d}	8.15±0.48^{f}	13.32±0.90^{bc}	SL	6.30±0.10^{a}	1499.94±9.41^{de}	2579.98±6.87^{de}	249.48±4.54^{g}	1356.97±7.77^{g}	1360.43±3.33^{ef}	1680.28±3.34^{e}	705.54±2.21^{k}
BTVSS	1038.37±8.35^{f}	45.21±0.48^{c}	79.74±0.53^{e}	6.26±0.18^{d}	14.20±0.20^{cd}	SL	6.20±0.12^{a}	2166.65±9.89^{f}	3726.25±6.81^{f}	384.62±4.41^{h}	608.30±2.82^{c}	1440.03±5.38^{f}	2440.22±4.35^{k}	579.32±2.22^{b}

KEY:

AP = Available phosphorus, TC = Textural class, OC = Organic carbon, OM = Organic matter, SL = Sandy loam, LS = Loamy sand, KPFSS =Kupafu Subsoil, KPFTS = Kupafu Top soil, KCTTS = Kuchita Topsoil, KCTSS = Kuchita Subsoil, BTVTS = Batavovogi Topsoil, BTVSS = Batavovogi Subsoil, Batavovogi Subsoil, BNGSS = Bunigi Subsiol, BNGTS = Bunigi Topsoil

Means with the same superscript within a column are not significantly different ($p > 0.05$)

CHAPTER FIVE

5.0 DISSCUSION OF RESULTS

5.1 Proximate Composition of the Inoculated and Uninoculated Cassava Products

5.1.1 Effects of inoculation on the crude protein contents the products

The result of percentage increase of crude protein contents of the microbially treated cassava products (‘fufu’ and ‘gari) obtained from Kontagora town (covering Wushishi, Bunigi, Kawo and Maito villages) is shown in Figure 4.1. The two fermenting organisms used were *Saccharomyces cerevisae* and *Lactobacillus bulgaricus.*From Figure 4.1, the percentage increase in crude protein was highest in the *S. cerevisea*-inoculated ‘fufu’ made from L30572 followed by Kpace Dzuru and Baba Iya having the values 88.28%, 76.44% and 84.17% respectively; ‘gari’ fermented with *S. cerevisea* produced from cassava pulp of TMS92/0326 variety followed with an increase of 52.48%. Similar increase were recorded in the ‘gari’ inoculated with *S. cerevisea* produced from Wahabi and Kpace Dzuru varieties (65.82% and 58.06% respectively). The *L. bulgaricus*-inoculated ‘gari’ products from Wahabi had 42.98% and TMS92/0326 cultivars had 60.7% elevation of crude protein. However, *L. bulgaricus*-fermented ‘fufu’ from Kpace Dzuru variety had 64.22% increase in crude protein, this was lower in percentage crude protein increase than the products inoculated with *S. cerevisea.* This indicated that *S. cerevisea* was a better fermenting organism than the *Lactobacillus bulgaricus* for protein enrichment of cassava products.

From Appendix II to X the protein content of the ‘fufu’ flour was much higher (two fold) than that of the gari in the inoculant treated, and three fold in the uninoculated cassava. The higher

crude protein values for the flour may be due to the effect of processing the pulp into gari, which involved pressing, sieving and frying the pulp. Some of the protein may have leached off during pressing and burnt off during frying (Akindahunsi *et al*, 1999).

The values of protein contents of *S. cerevisa*- and *L. bulgaricus*-fermented products have the mean ± standard deviation being 2.25±0.06% for 'fufu' obtained from 'Kpace Dzuru' and 9.95±0.07% for 'gari' produced from TME419 (Appendix I and III). These values were similar to the values reported by Oboh *et al* (2000). The values were also in conformity to the findings of other work, Oboh and Akindahunsi (2003) and the investigation of Ruthairat *et al*. (2010), which reported the values of protein to be 10.9% for flour and gari being 6.3%.

The increase in the crude protein content of the microbially treated products could be attributed to the possible secretion of some extracellular enzymes such as amylases, linamarase and cellulase (Ganiyu, 2006; Krisada, 2009) into the pulp by the fermenting organisms in an attempt to make use of the cassava starch as a source of carbon and the effectiveness of the microbes to convert these to proteinous materials. Apart from this, the increase in the growth and proliferation of the fungi/bacterial complex in the form of single cell proteins may possibly account for the apparent increase in the protein content of the products. In view of the significantly enhanced protein content in the microbial fermented cassava products, cassava products, regarded as having no nutritional value, could be integrated into our meals.

Furthermore, the values of crude protein of 'lafun'having the mean ± standard deviation of 0.89±0.04 for 'lafun' produced from kpace dzuru' and 4.62±0.91 for 'lafun' made from kpace bokun (neither fermented nor inoculted) were generally lower than those of other products fermented with the micoorganisms. This was so, possibly due to lack of the presence of

microorganisms that would have made more proteins available in the product (Appendices II, III and IV). Also, the local variety referred to as 'Baba Iya', which was reported to be the most cyanogenic of all the varieties studied, was identified as one of the highest in percentage increase of 83% (Figure 4.1). This showed the level of effectiveness of the activities of microorganisms in fermentation of cassava pulps. . It was observed that there was a significant increase ($P < 0.05$) in the protein content of the cassava products treated with the organisms compared with those fermented but not microbially inoculated (Duccan multiple range test).

Figure 4.2 presents the crude protein percentage increase in the cassava products of Bida samples. *L. bulgaricus*-treated 'fufu' from 'Kpace dzuru' variety showed the highest increase, being 95.45%. Of all the *S. cerevisae* treated products, 'fufu' from L30572 variety recorded the highest increase of 88.04% in the percentage of crude protein. This trend, coupled with similar higher values recorded in remarkable number of other products from various varieties made *S. cerevisae* the better fermenting organism to improve the nutritive values of cassva products, particularly 'fufu'. The Figure, also indicated 'fufu' products appeared to have more protein by the activities of both fermenting organisms. These trends corresponded with the report of Oboh and Elusiyan (2007) who evaluated the ability of pure strain of *Rizopus oryzae* and *Saccharomyces cerevisae* to alter the nutritional quality of cassava flour produced from low- and medium-cyanide varieties of cassava tuber. The results recorded a significant increase ($p < 0.05$) in protein content of all fermented products.

Considering the protein content shown in Appendices V, VI and VII, the range were 1.05±0.03 for 'fufu' produced from TME419 to 7.85±0.12 for 'fufu' obtained from TMS92/0326. These values were in agreement with values reported by Oboh *et al.* (2002), Okpako *et al.* (2008) and

Oboh and Elusiyan (2007) in similar investigations. The trend remained the same throughout, with more of 'fufu'products from different varieties being more enhanced with more protein, and *S. cerevisae* proved to be better efficient fermenting organism.The values obtained in this study are in agreement with the values reported by Oboh *et al.* (2002) and Oboh and Elusiyan (2007).

Result of the crude protein of the Suleja obtained cassava products are presented in Figure 4.3. The result showed that *S. cerevisae*-treated 'gari' of the improved variety (TMS92/0326) had the highest percentage increase in crude protein (82.5%). Other samples with significantly higher levels of percentage increase included 'Wahabi's *L. bulgaricus* inoculated 'gari' (64.4%), 'Wahabi's *S. cerevisae*-treated 'gari' (52.0%), *L. bulgaricus*-treaed 'fufu' from 'Baba Iya' (50.4%), TME419's *S. cerevisae-*treated 'fufu' (53%) *S. cerevisae*-inoculated 'fufu' from 'Karimugi (52%), 'Dan warri's *S. cerevisae*-inoculated 'gari' (80.1%), L30572's *L. bulgaricus*-treated 'gari' (54.2%), *L. bulgaricus*-fermented 'fufu' obtained from 'Dan Warri' (76%), 'Kpace Dzuru's *S. cerevisae*-treated 'fufu' (78.7%) *S. cerevisae*-inoculated 'fufu' from L30572 (64.2%) *L. bulgaricus*- fermented 'fufu' produced from L30572 (52.5%). When considering the values of crude protein contents of microbial fermentation presented in Appendices VIII, IX and X which had the ranges 3.58±0.03% for gari produced from 'Karimugi' to 10.28±0.23% for gari made from TMS92/0326, it was observed that these values were within the range given by Tilahun *et al*. (2013) and Fagbemi and Ijah (2006), which had values that were also as high as 10.00%.

Furthermore, the trend of the relationship between protein content and microbial fermentation remained similar as earlier pointed out. *S. cerevsea* showed greater tendency to improve the protein values of products fermented with it. Also, the 'fufu' products experienced higher values of percentage increase. One of the possible reasons for the ability of *S. cerevisae* to cause a

higher increase in protein could be that the culture condition favours the growth of S. cerevisae more than *L. bulgaricus*. In addition, it may be that S. cerevisae would tolerate the acidic environment and the presence of cyanide than *L. bulgaricus* Oboh and Elusiyan (2007). There was a significant increase ($P < 0.05$) in crude protein content of the fermnted products.

5.1.2 Effect of inoculation on the crude fibre content of the product

Figure 4.4 represents the percentage decrease in crude fibre of microbially obtained 'fufu' and 'gari' products produced from Kontagora cassava samples. The percentage decrease was highest in *S. cerevisea*-fermented 'fufu' from 'Karimugi' variety (78.33%), and lowest in *L. bulgaricus*-inoculated 'gari' produced from the same variety (10.34%.). It was observed from Figure 4.2 that 'fufu' and 'gari' products from most varieties treated with *S. cerevisea* showed higher reductions in crude fibre content. From the Appendices I, II and III, it was indicated that crude fibre values for *S.cerevisae* treated 'fufu' products ranged from 0.89±0.30% produced from 'Baba iya' and 2.24±0.10% obtained from 'karimugi' varieties. In the same vein 'fufu' products were more affected in crude fibre content reductions than found in the 'gari products. These findings agreed with the result reported by Tilahun *et al*. (2013) with percentage decrease in crude fibre being given as 73.8% in Qulle and 72% in Kello varieties analysed. The result showed statistical decreease ($P < 0.05$) in crude fibre contents of the porducts inoculated.

The decrease in crude fibre content by microbial fermentation was due to release of microbial enzymes that can hydrolyze crude fibre into simple sugars such as monosaccharides and disaccharides (Tilahun *et al*., 2013), and the effectiveness of the microbes to make use of these as a source of carbon to convert the fibres to proteinous material.

Figure 4.5 shows the percentage crude fibre decrease for all fermented products of Bida samples site. The percentage decrease for the *L. bulgaricus* treated 'fufu' obtained from TME419 was 71.3% , *L. bulgaricus*- inoculated 'fufu' from 'Wahabi' had 38.7%, *L. bulgaricus*-fermented 'fufu' from 'Dan warri' recorded a decrease by 52.3% and *S. cerevisae*-treated 'fufu' produced from L30572 achieved a 71.1% reduction. As for the 'gari' inoculated samples, the results indicated that 'gari' fermented with *S. cerevisae* obtained from TMS92/0326 had the crude fibre decreased by 38.7%, 'gari' inoculated with *L. bulgaricus* produced from TMS92/0326 was decreased in crude fibre by 35.6%, *L. bulgaricus*-treated 'gari' from 'Kpace Bokun' was found to be 61.6% reduced in crude fibre, 'gari' treated with *S. cerevisae* from 'Baba Iya' achieved 56.0% reduction, 'gari' fermented with *L. bulgaricus* from 'Dan Warri' had 37.8% reduction, *L. bulgaricus* -treated 'gari' produced from L30572 attained 35.1% loss in crude fibre, and *S. cerevisae*-inoculated 'gari' produced from 'Dan Warri' had 34.0% loss, these values are comparable with the findings of Tilahun *et al*. (2013). The values decreased significantly well in treated 'fufu' products.

The Suleja samples processed to cassava products had the crude fibre composition in 'fufu' and 'gari' subjected to *L. bulgaricus* and *S. cerevisae* treatment being represented in Figure 4.6. The trend indicated a similar pattern of percentage decrease in crude fibre content for the fermented products with inoculants. However, the percentage decrease was highest in Baba Iya's 'fufu' (85.39%) fermented with *S. cerevisae,* TME419's and Dan Wari's 'fufu' (81.96% and 82.25% respectively), and Kpace Bokun's 'gari' (61.58%) inoculated with *L. bulgaricus,* while *S. cerevisae*-treated 'gari' from Baba Iya markedly recorded a 60.98% reduction in crude fibre. From these observations, it could be concluded that *L. bulgaricus* showed to be a better

inoculant and does degrade fibrous component of cassava, and as usual, 'fufu' products were more affected with the action of these microbes.

5.1.3 Effect of inoculation on the crude fat content of the products

Figure 4.7 presents the effects of the inoculants on the percentage increase of crude fat in the microbially inoculated 'fufu' and 'gari' products produced from Kontagora cassava samples. From the results, there was a significant increase ($P < 0.05$) in crude fibre content of 'fufu' products with the highest percentage increase of 98.5% occurring in 'fufu' produced from 'Wahabi' inoculated with *L. bulgaricus*. The highest values of 7.55 ± 0.12 for 'fufu' got from TMS92/0326 inoculated with *S. cerevisae* and the lowest value of 1.17 ± 0.11 for 'fufu' produced from 'wahabi' were recorded in the Appendices II, III and IV. However, the products were enriched when inoculated with both *L. bulgaricus* and *S. cerevisa* in 'fufu' products (97.50% and 98.54% were highest values of crude fat in 'fufu' recorded as a result of the action of *L.* bulgaricus and 98.54% and 94.73% were the values obtained in the same product by the action of *S. cerevisae*). This showed that the two organisms had potency to enhance crude fat content of 'fufu' than'gari products.

Crude fat content of the fermented products (uninoculated) were found to have the mean ± standard deviation of 0.14 ± 0.01% for 'fufu' from naturally fermented 'baba iya' variety and 7.68±0.22% for 'fufu' from TMS92/0326 variety inoclated with *L. bulgaricus* (appendices II and III). These result is in conformity with the result reported by Oboh *et al.* (2000), who used *Aspergillus niger* to treat cassava products, and recorded crude fat content (flour (5.7±0.1%) and gari (4.0±0.3%). The results also agree with the findings of other work, Oboh and Akindahunsi (2003) whose values indicated fat for flour was 4.5% and gari has 3.0%. The account of the

high increase in crude fat content could partly be attributed to cell increase of the fermentation. In addition, there could be possible transformation of carbohydrate to fat brought about by the activities of the microorgansms (Krisada, 2009). It was also reported that certain fungi can produce microbial oil during fermentation.

The result of crude fat percentage increase in the microbially produced 'fufu' and 'gari'products of Bida samples is shown in Figure 4.8. The result indicated high potency of the fermenting organisms to improve the crude fat content of the fermented products. The percentage increase in the products indicated that there was a high significant elevation in crude fat for the 'gari' inoculated with *S. cerevisae* from 'Baba Iya' (75.87%), 'fufu' fermented with *L. bulgaricus* obtained from Baba Iya (84.9%), 'fufu' fermented with *L. bulgaricus* from 'Kpace Bokun' (95%), 'fufu' treated with *S. cerevisae* from 'Baba Iya' (63.3%), 'gari' obtained through inoculation with *L. bulgaricus* from 'Kpace Dzuru' (51.6%), 'gari' treated with *L. bulgaricus* from 'karimugi' (67.94%), 'gari' fermented with *L. bulgaricus* from TME419 (80.38%), 'fufu' inoculated with *S. cerevisae* from TME419 (86.7%), and 'fufu' produced from TME419 through treatment with *L. bulgaricus* (60%), compared to the uninoculated counterparts

Figure 4.9 presents the result of crude fat obtained for 'fufu' and 'gari' products from Suleja province through microbial fermentation with *S. cerevisae* and *L. bulgaricus.* The *L. bulgaricus* treated 'fufu' from L30572 showed the highest percentage increase in crude fat (96.5%) and the lowest value was from TMS92/0326 *S. cerevisae*-treated 'gari' (0.21%). The 'fufu' fermented with *S. cerevisae* from L30572, TMS92/0326, TME419 and 'gari' from 'Baba Iya' and 'kpace bokun' recorded 62.6%, 53.6%, 55.1%, 82.7% and 72.4% percentage increase in crude fat respectively. The 'fufu' treated with *L. bulgaricus* obtained from Kpace Bokun and 'gari' from

Wahabi showed percentage increase of 54.9% and 48.7% in crude fat respctively. Although, the 'fufu'products still showed higher tendency for nutrient enhancement, reverse is the case with *L. bulgaricus* which had, to a large extent, proved to have greater ability to increase crude fat of the products treated with it. This may be as a result of the organism's tendency to produce microbial oil during fermentation (Irtwange and Achimba, 2009)**.** Eugene *et al.* (2008) reported similar results. The results indicated that there was a significant percentage increase ($p < 0.05$) in fat for the samples fermented with *S. cerevisae* and *L. bulgaricus.*

5.1.4 Effect of inoculation on the carbohydrate content of the products

The result of percentage decrease in carbohydrate contents of the Kontagora obtained cassava products is depicted in Figure 4.10. Highest percentage decrease in the carbohydrate was found in *S. cerevisae*-inoculated 'fufu' produced from 'Karimugi' and that from 'Kpace Kokun subjected to the same microbial treatment, with a decrease of 18.10% and 17.69% respectively. However, there was no significant difference ($P > 0.05$) between the values of carbohydrate content obtained for both the inoculated and uninoculated products (Appendices II, III and IV). Among the values for the inoculated, the highest and the lowest values with the mean ± standard deviations were 93.06 ± 0.04 for fufu produced from 'Kpace Kzuru' and 83.09 ± 0.01 for gari made from 'Kpace Bobkun' respectively. The decrease in carbohydrate content on inoculation could be attributed to the ability of the fungal and the bacterial complexes to hydrolyze starch into glucose and ultimately the glucose will be used by the same organisms as a carbon source to synthesize fungi and bacterial biomass rich in protein. The proportionate increase in the protein content in cassaava pulp could also account for the decrease in the carbohydrate content (Ahaotu *et al*., 2011; Ganiyu, 2006). From the results, there was no significant decrease ($P > 0.05$) in the

carbohydrate content of the cassava products fermented with the *S. cerevisae* and *L. bulgaricus*, when compared with the naturally fermented products (Appendices II, III and IV).

Similarly, Figure 4.11 depicts the result obtained for percentage decrease in carbohydrate of 'fufu' and 'gari' products obtained from Bida town subjected to microbial treatment. There was no significant decrease ($P > 0.05$) in the carbohydrate content of the cassava products fermented with *S. cerevisae* and those by *L. bulgaricus*, when compared to the carbohydrate content of the naturally fermented products (Dumcan multiple range test). The percentage decrease ranged from 9.7% in the *L. bulgaricus*-treated 'gari' from TME419 to 0.01% in the *L. bulgaricus* inoculated 'fufu'produced from 'Karimugi'. Moreover, the result indicated that 'gari' products had more reduction in the carbohydrate content of the microbially treated cassava products. Also, *L. bulgaricus* had greater ability to bring about reduction in carbohyderate content.

The result of levels of percentage reduction in carbohydrate of 'fufu' and 'gari' products microbially fermented is presented in Figure 4.12. Although the percentage decrease was significantly low ($P > 0.05$) in the inoculated products, the decrease was almost equivalent in proportions in the 'gari' and 'fufu' products. Also, another obvious trend is the fact that *S. cerevisea* proved to a better fermenting organism to achieve more nutritious cassava products. The decrease could be attributed to the ability of the fungi/bacterial complex to hydrolyse starch into glucose and ultimately the glucose will be used by the same organisms as a carbon source to synthesize fungi/bacterial biomass rich in protein. Simlar reports were given in related findings of Aro and Aletor (2008), Oboh (2007) and Akindahuhsi *et al*. (1999).

5.1.5 Effect of inoculation on the moisture composition of the products

The result of percentage moisture composition of the various products obtained through microbial fermentation of Kontagora cassava samples is presented in Figure 4.13. The result indicated no clear trend was obtained for the moisture composition of the cassava products due nto inoculation after fermentation. Some products showed percentage increase while others showed percentage decrease. This indicates a very poor relationship between moisture content and fermentation. Moisture removal in cassava products is a function of many factors such as temperature, time, humidity and season. The available moisture in cassava products solely depends on the degree of dryness during drying and frying of 'gari' and drying of 'fufu'. Generally, well dried materials store well as there would be no free moisture to encourage micro-organisms multiplication, which otherwise would have had adverse effect on the quality of the products (Irtwange and Achimb, 1990). Therefore, moderate values obtained was an indication that these products would have higher shelf lives. Highest moisture content of 7.88 ± 0.04% was recorded in 'fufu' obtained from TMS92/0326 inoculated with *L. bulgaricus* and the highest value of 7.80 ± 0.04% was obtained for gari produced from the same variety (Appendices II, III and IV). These values were less than the values reported by Fayemi and Ojokoh and Okpako *et al.*(2008).

5.1.6 Effect of inoculation on the ash content of the products

Figure 4.16 shows the percentage ash content in 'fufu' and 'gari products produced through microbial fermentation of Kontagora cassava samples. Like the moisture content, there was no clear trend among the values obtained, which indicated a poor relationship between ash content and fermentation. The extent of percentage increase in ash was more pronounced in 'fufu'

products produced from the varieties analysed. *S cerevisea* fermentation of cassava increased ash content of both products as examplified in *S. cerevisea*-inoculated 'fufu' obtained from 'kpace dzuru'with a value of 67.73%, *S. cerevisea*-treated 'fufu' made from 'Baba Iya' recorded 69.83%, *S. cerevisea*-treated 'fufu' produced from TME419 had 61.20% and *S. cerevisea*-inoculated 'fufu' made from TMS92/0326 recorded 51.61%.

A comparative analyses between the ash contents of in this study and in the related work by others, indicated that the values obtained correspond with the findings of Aro and Aletor (2006), but less than the values obtained by Akindahunsi *et al*.(1999) (Appendices II, III and IV).

5.1.7 Effect of inoculation on the total dry matter (TDM) of the products

Result of the total dry matter (TDM) content of 'fufu' and 'gari' produced from various varieties of cassava of Kontagora is presented in the Figure 4.19, indicating the percentage compositions. There was also a discernable relationship between TDM and fermentation like the ash and moisture compositions. Some percentage values increased while some decreased. For example, *S. cerevisea*-treated 'gari' produced from 'wahabi increased by 1.11% while *S. cerevisea*-treated 'fufu' obtained from the same variety got reduced by 0.70%. Appendices II, III and IV for Kontagora obtained products showed that TDM mean value was 92.12 ± 0.10% for 'fufu' prepared from TMS92/0326 through *L. bulgaricus* inoculation and 97.84 ± 0.35% for 'fufu' obtained from 'Baba Iya' through *L. bulgaricus* fermentation. This mean value was lower than the meaan values recorded by Krisada *et al.* (2009) which had values ranging from 65.7% to 89.4% increase.

Figures 4.14, 4.17 and 4.20 represent the results of percentage compositions of moisture, ash and total dry matter (TDM) respectively of 'fufu' and gari products of cassava samples of Bida. In the same vein, there existed no clear trend of relationship between these parameters and the microbial fermentation. From Appendices V, VI and VII, it was observed that the range of the moisture, ash and TDM recorded for fermented products was from 0.58 ± 0.37% for 'fufu' produced from 'Wahabi' inoculated with *S. cerevisae* to 2.80 ± 0.20% for 'gari' obtained from TMS92/0326, 3.62 ± 0.04% for 'gari' made from TMS92/0326 and treated with *S. cerevisae* to 8.55±0.06% for 'fufu' produced from L30572 fermented with *L. bulgaricus* and 91.45 ± 0.01% for 'fufu' obtained from L30572 and inoculated with *L. bulgaricus to* 96.38 ± 0.22% for 'gari' produced from TMS92/0326 treated with *S. cerevisae* respectively.

Figures 4.15, 4.18 and 4.21 show the results of moisture, ash and total dry matter (TDM) compositions of 'fufu'and 'gari' treated microbially of Suleja samples. From the result, there was a discerned relationship between the microbial fermentation and the moisture, ash and TDM. The obvious trend of composition in Figures 4.15, 4.18 and 4.21 was the occurence of both percentage loss and increase in moisture, ash or TDM. In addition, all products subjected to *S. cerevisae* fermentation were highly nutritionally improved. Moreover, the values of moisture, ash and TDM contents presented in Appendices VIII, IX, and X revealed some degree of smilarities between the findings of this work and the related research carried out by Okoro (2007) and Akoja and Mohammed (2011).

5.2 Anti-nutrient Contents of the Inoculated and Uninoculated Cassava Products

5.2.1 Effect of inoculation on the cyanide content of the products

The result of cyanide contents of 'fufu' and 'gari' products produced through microbial fermentation of selected varieties of cassava samples from Suleja site is presented in Figure 4.22. The percentage decrease in cyanide content was highest in Baba Iya's *S. cerevisae*-treated 'gari' (70.43%) and lowest in 'fufu' produced from 'Kpace Dzuru' through *S. cerevisae* inoculation (2.85%). Higher percentage loss level of cyanide were also recorded for 'Karimugi's *S. cerevisae*-fermented 'fufu' (65.1%), *S. cerevisae* inoculated 'fufu' from TMS92/0326 (66.7%), 'fufu' treated with *L. bulgaricus* from TMS92/0326 (63.7%), *L. bulgaricus*-fermented 'gari' produced from 'Kpace Bokun' (38.6%), Wahabi's 'gari inoculated with *S. cerevisae* (66.2%), *L. bulgaricus*-treated 'fufu' from 'Baba Iya' (56.2%), *L. bulgaricus*-treated 'gari' from L30572 (54.2%) and 'fufu'fermented with *L. bulgaricus* from the same variety of L30572 (52.1%).

It was evident from the result that the level of cyanide reduction by the action of *L. bulgaricus*-aided fermentation was not significantly different ($P > 0.05$) from the ones brought about by *S. cerevisae*-faclitated fermentation (Duncan multiple test). However, the ability of the two organisms to bring about reduction of cyanide in 'fufu' products was found to be more effective than in 'gari' products. The results of this investigation corroborate with the findings of Tilahun *et al*. (2013), Ebuchi *et al*. (2005), Fagbemi and Ijah (2006) and Eustace and Dorothy (2000), though the authors used different microorganisms for the fermentation. It was also obvious that the values of cyanide contents of non-fermented lafun products were significantly higher than the gari and fufu products subjected to natural and micrbial fermentation. There were also signficant differences between the values obtained in the natural and microbial fermented products. This

trend was found to be the same with other antinutrient constituents determined (appendices XI, XII and XIII).

The reduction in cyanide is attributed to several factors including:

(i) Changes in the texture in the plant tissues which make it possible for vacuole-bound cyanogenic glycosides to diffuse and come in contact with membrane-bound linamarase.

(ii) Increase in β-glycosidase activity in cassava tissue, and

(iii) Utilisation of cyanogenic glycosides and the breakdown products by fermentation microorganisms. When cyanogenic glucoside is exposed to linamarase, it is cleaved to produce hydrogen cyanide which evaporates or pressed out during cassava processing (Asegbeloyin and Onyimonyi, 2007; Eustace and Dorothy, 2000). Moreover, cassava processing which involves grating, fermentation and roasting can lead to a reduction in the total cyanide more in 'gari' (Akindahunsi *et al.*, 1999). The results indicated that there was a significant decrease ($P > 0.05$) in cyanide content of the fermented products as a result of inoculation.

Figure 4.23 presents the result of cyanide composition (percentage decrease) of the fermented cassava products - 'gari', 'fufu' subjected to microbial fermentation of Kontagora samples. The cyanide content decreases significantly ($P < 0.05$) after fermentation. Percentage reduction was highest in 'gari' fermented with *S. cerevisae* produced from 'Baba Iya' (68.64%) and lowest in 'fufu' treated with *L. bulgaricus* (1.01%). The results showed similar trend to the ones obtained for protein contents of Suleja samples, only that the percentage reduction was higher in Kontagora samples. It was also evident from the result that the level of reduction of cynide by

the action of *L. bulgaricus*-aided fermentation was not significantly different from the one brought about by *S. cerevisae*-inoculated fermentation.

However, the ability of the two organisms to bring about reduction of cyanide in 'fufu' products was found to be more effective than in 'gari' products. The results of this investigation were similar with the findings of Tilahun *et al*. (2013), Ebuchi *et al*. (2005), Fagbemi and Ijah (2006) and Eustace and Dorothy (2000), though the authors used different microorganisms for the fermentation. It was also obvious that the values of cyanide contents of non-fermented lafun products were significantly higher than the gari and fufu products subjected to natural and microbial fermentation. There were also signficant differences between the values of natural and microbial fermented products.

The result of cyanogenic glycoside contents of fermented products of Bida samples is preseted in Figure 4.24. The highest percentage reduction was found in *L. bulgaricus* inoculated 'fufu' produced from TMS92/0326 (86.17%) and the leaest reduction occured in *S. cerevisae* treated 'gari' from TMS92/0326 (1.30%). The result further indicated that the level of cynide reduction by the action of *L. bulgaricus*-aided fermentation was significantly different from the ones brought about by *S. cerevisae*-faclitated fermentation. products fermented with *S. cerevisae* recorded higher reductions. However, the ability of the two organisms to bring about cyanide reductions in 'fufu' products was found to be more effective than in 'gari' products. The result of this investigation is similar to the findings of Oboh and Elusiyan (2007), Ebuchi *et al*. (2005), Fagbemi and Ijah (2006) and Eustace and Dorothy (2000), though the authors used different microorganisms for the fermentation. It was also obvious that the values of cyanide contents of non-fermented lafun products were significantly higher than the 'gari' and 'fufu' products

subjected to natural and microbial fermentation, though the values recorded for microbial fermented products were generally the lowest. There were also signficant differences between the values of naturally and microbially fermented products. This trend was found to be the same with other antinutrients constituents determined (Appendices XVII, XIII and XIX). These results were similar to the findings of Asegbeloyin and Onyimonyi (2007) and Okoro (2007), though, the focal point of their investigations was on biofortification of cassava products through other proteinous sources. There were significant losses ($p < 0.05$) of the cyanide of samples treated with either *S. cerevisae* or *L. bulgaricus.*

5.2.2 Effect of inoculation on the oxalate content of the produicts

Figure 4.25 presents the result of oxalate contents of 'fufu' and 'gari' products obtained through microbial treatment of Suleja samples. The *S. cerevisae*-inoculated 'gari' produced from 'Karimugi' had the highest percentage increase (54.05%) when compared to the uninoculated counterparts. From the results, reduction in oxalate was more pronounced in 'gari' products.This was attributed to processing method of 'gari' which involves grating, fermentation and roasting thereby leading to a reduction in oxalate. When reference was made to Aappendices XI, XII and XIII , oxalate content decreased from 4.20 ± 0.08 mg/100g to 1.84 ± 0.21 mg/100g dry sample. For both the 'fufu' ang 'gari'. The levels of oxalate reduction in this study wsas less than those obtained by Tilahun *et al***.** **(**2013). The results also showed significant decrease in the percentage content of oxalate ($p < 0.05$) as a result of microbial fermentation.

The result of the level of percentage decrease of oxalate in cassava products – 'fufu' and 'gari' – of Kontagora samples, inoculated separately with *S. cerevisae* and *L. bulgaricus* is presented in Figure 4.26. The *S. cerevisae*-fermented 'gari' produced from 'Karimugi' (49.11%) recorded the

highest percentage oxalate reduction while the 'fufu' inoculated with *L. bulgaricus* obtained from *TME419* (0.76%) had the least percentage reduction in oxalate. As pointed out earlier in Figure 4.26, these results also indicated that reduction of oxalate was more in the 'gari' products.This was linked to the processing method of 'gari' which involves grating, fermentation and roasting thereby leading to reductions in oxalate. Considering Appendices XIV, XV and XVI, oxalate content decreased from 11.23 ± 1.31 mg/100g to 5.00 ± 0.65 mg/100g dry sample in 'gari'. This level of oxalate decrease was less than the values obtained by Tilahun *et al***.** **(**2013). Also, this value was less than the values obtained for 'lafun' products which was neither naturally fermented nor microbially fermented, and the 'gari' and 'fufu' products that were only subjected to natural fermentation.

Figure 4.27 constitutes the result of oxalate percentage decrease in Bida samples microbially fermented ('fufu' and 'gari'). By comparing the percentage decreases in oxalate for the Bida samples with the reductions in Kontagora and Suleja samples, it was observed that the reduction in oxalate was higher in the Kontagora and Suleja samples than the Bida samples. Also, contarary to the previous trend, 'fufu' products were more effectively detoxified of oxalate compared to 'gari' products. The result further pointed out that the level of oxalate reduction by the action of *L. bulgaricus*-aided fermentation was not significantly different from the ones brought about by *S. cerevisae*-facilitated fermentation. There was also signficant differences between the values of oxalate inthe natural and microbial fermented products. (Appendices XVII, XVIII and XIX).

5.2.3 Effect of inoculation on the phytate composition of the products

The levels of percentage decrease of phytate microbially fermented cassava products - 'fufu' and 'gari' – of Suleja samples are presented in Figure 4.28. It was observed from the results that the highest percentage reduction was recorded in TMS92/0326 cultivar's 'fufu' treated with *L. bulgaricus* (53.81%) and the least reduction was in 'gari' produced from 'Wahabi' through *L. bulgaricus* fermentation (1.91%). Other percentage reductions in phytate ranged from 38.24% to 1.90% of *L. bulgaricus*- treated 'gari' from 'Dan Warri' and that in 'Wahabi' respectively. The phytate content was observed to have ranged from 146.50 ± 0.45 mg/100 g to 367.00 ± 4.70 mg/100g of 'gari' fermented with *L. bulgaricus from* TMS92/0326 and from TME419 cultivars respectively (Appendix XI). These values conformed to those obtained by Tilahun *et al*. (2013) which ranged from 173.57 ± 0.56 mg/100g to 104.48 ± 0.68 mg/100g for Qulle flour sample and Kello varieties respectively.

From the Appendices XI, XII and XIII, it was obvious that the ability of the organisms to detoxify 'fufu' products of phytate is higher than in the 'gari' in most cases. The decrease in the phytate content of the microbial fermented cassava flour could possibly be attributed to the secretion of the enzyme phytase by microbes during fermentation. These enzymes are capable of hydrolysing phytate, thereby, decreasing the phytate content of the cassava flour (Oboh and Elusiyan, 2007). The variation in the level of decrease in the phytate content of the products by each microorganism indicated that the enzyme activity varies with organism.

Levels of percentage reduction in phytate in the microbially treated 'fufu' and 'gari' products of Kontagora samples are shown in Figure 4.29. The reduction in *S. cerevisae*- treated 'fufu' from 'Kpace Dzuru' was the highest (40.76%) and 'karimugi's *L. bulgaricus* fermented gari had the

lowest reduction (0.78%). From Figure 4.29, it was also obvious that the ability of the organisms to detoxify 'fufu' products of phytate was higher than in the 'gari' in most cases. The phytate contents in Appendices XIV, XV and XVI indicated that it ranged from 101.50 ± 0.45 mg/100g and 298.00 ± 4.70 mg/100g in 'gari' fermented with *L. bulgaricus* from L30572 and in the 'Kpace Bokun' cultivars respectively. Also, phytate was highest in the unfermented 'lafun' products and lowest in the 'fufu' and 'gari' products subjected to microbial fermentation. These values of the fermented products agreed with the values obtained by Tilahun *et al*. (2013) which had values that ranged from 173.57 ± 0.56 mg/100g to 104.48 ± 0.68 mg/100g for Qulle flour sample and Kello varieties respectively. The decrease in the phytate content of the microbial fermented cassava flour could possibly be attributed to the secretion of the enzyme phytase by microbes during fermentation. These enzymes are capable of hydrolyzing phytate, thereby, decreasing the phytate content of the cassava flour (Oboh and Elusiyan, 2007).

The reduction in phytate for the 'fufu' and 'gari' products fermented from the Bida samples are presented in Figure 4.30. The highest value was recorded in *S. cerevisae*-fermented 'fufu' made from TMS92/0326 (72.03%). There were no significant differences between the ability of the two organisms to reduce phytate in the cassava products from which they were fermented, nor was there significant differences between .the potency of the two cassava products to get detoxified.

Expectedly, the values recorded for 'lafun' products (the unfermented products) and the values obtaied for 'gari' and 'fufu' products being naturally inoculated were higher than the values obtained for 'gari' and 'fufu' products that were microbially treated (Appendices XVII, XVIII and XIX).

5.2.4 Effect of inoculation on the tannin contents of the products

Figure 4.31 presents the of tannin contents of the microbially fermented 'fufu' and 'gari' products obtained from various cassava varieties cultivated at Suleja area. The percentage loss in tannins occurred significantly in all the cultivars fermented with *L. bulgaricus* and *S. cerevisae*. For tannins, the reductions were markedly high in *L. bulgaricus*-treated 'fufu' from TMS92/0326 (34.67%), *S. cerevisae*-inoculated 'gari' from 'Kpace Bokun' (33.86%), 'wahabi' (30.33%), *L. bulgaricus*-treated 'gari' produced from 'Wahabi' (47.81%), 'Baba Iya' (33.27%) . Tannin contents of 'Dan Warri's 'gari' treated with *S. cerevisae* and that of 'fufu' of the same 'Dan Warri' decreased by 43.12% and 51.73 % respectively. Decrease in tannin content can be attributed to the degradation of polyphenols as a result of different microorganisms that are involved in fermentation and the corresponding microbial enzymes that are released during fermentation period (Tilahun *et al*., 2013).

The result of tannin contents obtained for Kontagora cassava samples microbially fermented to'gari' and 'fufu' is presented in Figure 4.32. Tannin content recorded the highest percentage reduction in TME419's *S. cerevisae*-treated 'fufu' (36.76%) and the lowest reduction was in 'gari' inoculated with *L. bulgaricus* from 'Baba Iya' (0.67%). It was also observed from the results that, like the trend in most cases, that the gari products recorded higher values irrespective of the organism used. Considering the values of tannin contents from Appendices XIV, XV and XVI, it was observed that the values of tannin ranged from 2.03 ± 1.04 mg/100g to 9.53 ± 2.40 ¯mg/100g for 'gari' made from 'Dan Warri' inoculated with *S. cerevisae* and 'gari' produced from 'Karimugi' not microbially treated. There was a significant difference between the percentage obtained for the microbially treated products compared to the untreated ones.

Levels of tannin in the 'lafun' products was the highest because the products were neither microbially fermented nor naturally fermented.

Figure 4.33 shows the result of the reduction of tannin in 'gari' and 'fufu' products being microbially fermented using various varieties of cassava cultivated at Bida sampling site. The highest decrease occured in *L. bulgaricus*-inoculated 'gari' produced from TMS92/0326 (47.74%) and *L. bulgaricus*-fermented 'fufu' from 'Baba Iya' (48.14%), and the lowest reduction in tannin was recorded in *S. cerevisae* treated 'gari' obtained from 'Karimugi' (6.92%). From these results, itcan be inferred that the two organisms were good at bringing about a reasonable reduction in tannin for the 'gari' products than in 'fufu' products, while there were no appreciable differences between the abilities of the two organisms to reduce tannin contents in cassava products. Also of note is the significant differences between the microbially fermented products and those subjected to natural fermentation and the unfermented ones.

5.2.5 Effect of inoculation on the saponin composition of the products

The result of saponin contents of 'fufu' and 'gari' products produced from cassava samples of Suleja sampling point is presented in Figure 4.34. The result indicated significant reduction in 'gari'produced from 'Kpace Dzuru' and 'Dan Warri' through *L. bulgaricus* treatment (53.82% and 42.26% respectively), 'gari' obtained from 'Dan warri' and 'Kpace Dzuru' of *S. cerevisae* treatment (48.15% and 42.11% respectively). Moreover, saponin content of 'Baba Iya's 'fufu' of *L. bulgaricus* treatment, *S. cerevisae* fermented 'fufu' from 'Baba Iya' and that of TME419 was reduced by 58.90%, 92.69% and 33.19% respectively. However, there were significant differences ($p < 0.05$) between *S. cerevisae*-fermented 'gari' (30.33%) and 'fufu' (0.01%) produced from 'Wahabi' variety, *L. bulgaricus*-treated fufu (33.63%) and gari (12.04%)

obtained from L30572, ‘fufu’ (17.84%) and ‘gari’ (47.81%) produced from ‘Wahabi’, ‘fufu’ (5.87%) and gari (33.27%) made from ‘Baba Iya’, ‘fufu’ (34.67%) and ‘gari’ (7.62%) from TMS92/0326 and ‘fufu’ (6.33%) and ‘gari’ (23.71%) obtained from TME419.

Figure 4.35 represents the saponin contents for ‘fufu’ and ‘gari products produced through microbial treatments obtained from Kontagora samples.When considering the saponin content, the highest reduction occured *in S. cerevisae* inoculated fufu from ‘Dan Warri’ (52.29%) and the least reduction was in ‘gari’ treated with *L. bulgaricus* (2.43%). From these results it is obvious that *S. cerevisae* had the ability to detoxify casssava products more than the *L. bulgaricus,* since most of the treatments with *L. bulgaricus* recorded lower reductions in the anti-nutrient.

The result of saponins for ‘fufu’ and ‘gari products produced through microbial treatments obtained from Kontagora samples is presented in Figure 4.36. When considering the saponin content, the highest reduction occured *in L. bulgaricus* -inoculated (66.60%) ‘gari’ from ‘kpace bokun’ and the lowest value found in ‘fufu’ treated with *L. bulgaricus* produced from ‘kpace dzuru’ (0.86%). Expectedly as occurred in Figure 4.31, *S. cerevisae* had the ability to detoxify casssava products more than the *L. bulgaricus,* since most of the treatments with *L. bulgaricus* recorded lower reductions in the anti-nutrient.

5.3 Mineral Compositions of the Inoculated and the Uninoculated Cassava Products

5.3.1 Effect of inoculation on the zinc contents of the products

The result of the increase in the level of zinc in the microbially fermented products – ‘fufu’ and ‘gari’- obtained from Suleja cassava samples is presented in Figure 4.37. It was observed that both ‘fufu’ and ‘gari’ products subjected to the same microbial treatment appeared to show

significant difference in thier efficiency to be enriched with zinc, particularly for the *S. cerevisae*-treated 'fufu' product made from L30572 (53.59%) and *L. bulgaricus*-fermented 'fufu' produced from L30572 (48.57%). Noticeably, the ability of *S. cerevisae* to effectively increase the level of zinc in the products was not significantly different from the ability of *L. bulgaricus* to enrich the same products. Furthermore, there were significant differences between the products subjected to microbial fermentation and the uninoculated ones. These results were similar to the findings of Tilahun *et al*. (2013), Oboh and Elusiyan (2007), Oboh and Oladunmoye (2007) and Aro (2008). The result indicated that there was no significant increase in the zinc content ($P < 0.05$) in most products analysed as a result of microbial fermentation.

The result of the level of zinc percentage increase of the microbially fermented products – 'fufu' and 'gari'- obtained from Kontagora cassava samples area presented in Figure 4.38 It was showed that both the 'fufu' and 'gari' products subjected to the same microbial treatment appeared to show significant difference in thier tendencies to be enriched with zinc, particularly the *S. cerevisae*-treated 'fufu' product made from 'Kpace Dzuru (27.41%) and *L. bulgaricus*-fermented 'fufu' produced from 'Kpace Dzuru' (20.00%). This indicated that 'fufu' products from 'Kpace Dzuru' recorded highest in zinc. The ability of *S. cerevisae* to effectively increase the mineral contents of the products was significantly different in most cases from the ability of *L. bulgaricus* to enrich the same products. Furthermore, there were no significant differences between the products subjected to microbial fermentation and 'fufu', 'gari' and 'lafun' products not inoculated. The result revealed that there was no significant incrasese in the mineral ($P < 0.05$) in most products analysed.

The result of the percentage increase of zinc in the microbially fermented products – 'fufu' and 'gari'- obtained from Bida cassava samples is presented in Figure 4.39. It was also observed that both 'fufu' and 'gari' products subjected to microbial treatment appeared to show no appreciable difference in thier efficiency to get enriched with zinc, particularly for the *S. cerevisae*-treated 'fufu' product made from L30572 (20.18%) and *L. bulgaricus*-fermented 'fufu' produced from L30572 (14.09%). Invariably, the ability of *S. cerevisae* to make more zinc available in the products was not significantly different from the ability of *L. bulgaricus* to enrich the same product. Furthermore, there were significant differences between the products subjected to microbial fermentation and the uninoculated ones (Appendices XXVI, XXVII and XXVIII). The result indicated that there was no significant difference ($P > 0.05$) amogst the percentage values of most products obtained from the varieties studied.

5.3.2 Effect of inoculation on the level of magnsium content in the products

Figure 4.40 presents the result of magnesium contents in cassava-based products – "fufu' and 'gari' obtained from Suleja sampling site, and subjected to microbial treatments. From the result, there was a slight increase in percantage of magnesium in the products with 'gari' inoculated with *S. cerevisae* produced from TMS92/0326 having the highest amount of magnesium being 68.64% and the 'fufu' fermented with *L. bulgaricus* obtained from TME419 recorded the lowest amount of magnesium (1.92%). Appendices XX, XXI abd XXII revaeled that there was an appreciable difference between the cassava-based products microbially inoculated and those naturally treated and the unfermented ones. For example, the value recorded for 'gari' made from TME419 through *L. bulgaricus* fermentation (469.56 ± 3.82 mg/kg) is significantly different from the value obtained for the same 'gari' of the same cassava variety and subected to the same

microbial treatment (405.49 ± 4.22 mg/kg) as well as the value for the unfermented 'lafun' (429.83 ± 3.76 mg/kg) from the same variety. The grated cassava products - 'gari' - was observed to record lower percentage increase in'gari' produced from 'Kpace Dzuru' by *S.cerevisae* fermentation (14.24%) compared to the 'fufu' product produced from L30572 by the same microbial treatment (20.18%). There was no significant difference between the activities of the two organisms to enhance the nutritional quality of the products with respect to magnesium. It was also observed the there is dearth of information regarding the magnesium contents of cassava products in literature, so this result is vital for evaluating the relevance of fermentation in cassava processing.

Figure 4.41 presents the result of magnesium contents in cassava-based products – "fufu' and 'gari' obtained from Kontagora sampling area, and subjected to microbial treatments. The percentage increase of magnesium was highest in 'fufu' produced through *L. bulgaricus* fermentation of 'baba iya' (42.37%) and was least in 'fufu' made from Dan Warri and inoculated with *S. cerevsae (*1.60%). There was no significant difference ($P > 0.05$) between the activities of the two organisms to enhance the nutritional quality of the products with magnesium. Appendices XXIII, XXIV, XXV revaeled that there was no appreciable difference ($P > 0.05$) between the cassava-based products microbially inoculated and those naturally treated and the unfermented 'lafun' products.

The result of magnesium contents in cassava-based products – "fufu' and 'gari' obtained from Bida sampling site, and subjected to microbial treatments is presented in Figure 4.42. From the result, percentage increase in magnesium was reasonably high in 'gari' and 'fufu' (48.36% and 55.15% respectively) obtained from TME419 through *S. cerevisae* fermentation, 'gari and 'fufu'

(32.63% and 47.13% respectively) produced from TME419 inoculated with *L. bulgaricus*, 'gari' (41.16%) from 'Wahabi' through *S. cerevisae* fermentation and *L. bulgaricuss*-treated 'gari' and 'fufu' (45.31% and 52.71% respectively) obtained from 'Kpace Bokun'. Also, there was no significant difference in the abilities of the two organisms to add more magnesium to the fermented products. Furthermore, a reference to Appendices XXVI, XXVII and XXVIII indicated no significant difference ($P > 0.05$) between the magnesium contents of the cassava-based products microbially inoculated and those naturally treated as well as the unfermented 'lafun' products.

5.3.3 Effect of inoculation on the level of sodium composition in the products

The level of percentage increase of sodium in 'fufu' and 'gari products of Suleja samples is presented in Figure 4.43. A highest value of 51.67% was recorded in 'fufu' produced from 'Karimugi' through *L. bulgaricus* fermentation followed by a 44.79% increase in 'gari' obtained from TMS92/0326 through *S. cerevisae* inoculation while a least value of 0.89% for 'gar' produced from 'Kpace bokun' subjected to *S. cerevisae* fermentation. Also from the results, 'fufu' products recorded reasonable higher percentage increase than recorded for 'gari' products. Furthermore, the fermentation organism, *L. bulgaricus*, showed more efficiency in bringing about increase in sodium contents of both products. Appendices XX, XXI and XXII revealed that microbailly inoculated materials showed higher sodium contents. The findings comforms with those of Ayodeji (2005), Oboh and Elusiyan (2005) and Aro (2008), though their values were expressed in part per million (ppm) and percentage compositions.

The percentage increase of sodium in 'fufu' and 'gari obtained for Kontagora samples are presented in Figure 4.44. The highest percentage of sodium were increased in 'fufu' products of

TMS92/0326 treated with *L. bulgaricus* by 24.53%, 'Karimugi' fermented with *L. bulgaricus* (39.27%), 'Kpace Bokun' through *S. cerevisae* fermentation by 34%, L30572 subjected to *L. bulgaricus* fermentation by 39.28%, L30572 treated with *S. cerevisae* by 40.08%, 'Kpace Dzuru' inoculated with *S. cerevisae* by 45.46%, 'Kpace Dzuru' through *L. bulgaricus* treatment by 43.19%. Also from the result, the fermentation organisms, *L. bulgaricus* and *S. cerevisae*, demonstrated similar efficiency in bringing about increase in sodium contents of both products. Appendices XXIII, XXIV and XXV showed that microbail inoculated products had higher sodium contents. There were significant differences ($p < 0.05$) between the values recorded for most 'fufu' and 'gari products.

The result of increase in percentage of sodium in microbially fermented cassava products obtained from Bida sampling area are presented in Figure 4.45. These values of sodium ranged from 0.74% for 'gari' produced from 'dan warri' through *S. cerevisae* fermentation to 56.06% for 'fufu' made from 'kpace dzuru treated with *L. bulgaricus.* Though, the increase in percentage was not appreciably much with the two organisms, the increase was more with the materials treated with *L. bulgaricus.* Also of note was the sightly higher values of sodium recorded with 'fufu' products than the 'gari'materials. The results indicated that there were no significant differences in values amongst all the products determined.

5.3.4 Effect of inoculation on the level of potassium composition in the products

Figure 4.46 contains the result of the level of potassium percentage increase in 'fufu' and 'gari' products microbially fermented of Suleja cassava product samples. There was no significant difference between the percentage increase in some 'gari' and 'fufu' products subjected to *S. cerevisae* and *L. bulgaricus* fermentation. As usual, *S. cerevisae* fermentation proved to be more

promising in enriching cassava products – 'gari' and 'fufu' - than the *L. bulgaricus* fermentation. The highest increase in percentage was recorded in *S. cerevisae*-fermented 'fufu'obtained from 'kpace bokun' variety (47.13%) and lowest in 'fufu' produced from TMS92/0326 variety inoculated with *L. bulgaricus* (0.51%). Appendices XX, XXI and XXII showed that potassium content was highest in all the products microbially fermented (for example, 3411.13 ± 7.24 mg/kg recorded for microbially produced 'fufu' from TME419) than those only treated naturally (2688.55 ± 6.00 mg/kg for 'fufu' from TME419) and the 'lafun' products (2621.45 ± 7.38 mg/kg for 'lafun' from TME419) that were produced without fermentation.

Figure 4.47 contains the result of the level of potassium percentage increase in 'fufu' and 'gari' products microbially fermented of Kontagora cassava product samples. Percentage increase was found to be highest in 'gari' products of 'Baba Iya' and 'Dan Warri varieties'obtained through *S. cerevisae* fermentation (54.50% and 54.53% respectively), and the highest in the 'fufu' products of 'Wahabi'produced by *L. bulgaricus* fermentation (46.07%). The lowest value for 'fufu' however, was found in the 'fufu' produced from TMS92/0326 variety inoculated with *L. bulgaricus* (0.51%). There were significant differences between the values in''gari' and 'fufu' products subjected to *S. cerevisae* and *L. bulgaricus* fermentations. Here, the trend remained that *S. cerevisae* fermentations led to better enriched cassava products than the *L. bulgaricus* fermentated ones Similarly,. Appendices XXIII, XXIV and XXV indicated that potassium content was highest in all the products being microbially fermented than those that were only treated naturally and the 'lafun' products that were produced without fermentation.

The percentage increase of potassium in 'fufu' and 'gari products of Bida samples are presented in Figure 4.48. A highest value of 39.45% increase in potassium was recorded in 'gari' produced

from TME419 through *S. cerevisae* fermentation fermentation and a lowest value of 0.94% was found in 'fufu' made from TMS92/0326 through *S. cerevisae* inoculation. Moreover, the fermentation organisms, *L. bulgaricus* and *S. cerevisae*, showed similar efficiency in bringing about increase in potassium contents of both products. Appendices XXVI, XXVII and XXVIII revealed that microbially inoculated cassava recorded higher potassium contents, though, the differences between the values were not significant ($P > 0.05$). This findings comforms those reported by Ayodeji (2005), Oboh and Elusiyan (2005) and Aro (2008).

5.3.5 Effect of inoculation on the level of calcium composition in the products

The result of increase in percentage of calcium for microbially fermented cassava products obtained from Suleja sampling is are presented in Figure 4.49. These values of cacium ranged from 1.16% for 'fufu' made from L30572 and treated with *L. bulgaricus* to 17.21% for 'fufu' produced from 'Kpace Bokun' through *S. cerevisae* fermentation. Though the increase in percentage was not appreciably much with the use of the two organisms, but the increase was more with the materials treated with *S. cerevisae.* Also of note is the sightly higher values recorded with 'gari' products than the 'fufu'in the amount of 16.38% for 'gari' obtained from 'Kpace Dzuru' being the highest value of calcium and 0.62% for 'fufu' made from 'Karimugi' through *S. cerevisae* fermentation as the least value of calcium . The results indicated that there were no significant differences in percentage increase amongst all the products determined.

The result of increase of percentage in calcium for microbially fermented cassava products obtained from Kontagora sampling area are presented in Figure 4.50. The result indicated that there were no significant differences in values amongst all the products determined. These values ranged from 3.13% for 'gari' made from 'Karimugi' fermented with *S. cerevisae* and

21.67% for ‘fufu’ produced from ‘Kpace Bokun’ through *S. cerevisae* fermentation. Though the increase in percentage was not significantly much with the two organisms, the increase was more pronounced with the cassava treated with *S. cerevisae.* Results from Appendices XXIIi, XXIV and XXV indicated no significant differences (P > 0.05) between the microbially traeted products and the naturally fermented products, except the products derived from ‘Dan Warri’ variety Duncan test).

Figure 4.51 contains the results of the level of calcium percentage increase in ‘fufu’ and ‘gari’ products microbially fermented of Bida cassava samples.The values of calcium ranged btween 0.50% and (19.41%) in *S. cerevisae*-inoculated ‘gari’ obatained from ‘Karimugi’ and *L. bulgaricus*-inoculated ‘fufu’ produced from ‘Kpace Bokun’ respectively. There was no significant difference between the values of calcium in some ‘gari’ and ‘fufu’ products subjected to *S. cerevisae* and *L. bulgaricus* fermentation. In Appendices XXVI, XXVII and XXVIII, it indicated that calcium content was higher in all the products microbially fermented than those only treated naturally and the ‘lafun’ products that were produced without fermentation.

5.3.6 Effect of inoculation on the level of iron composition in the products

Levels of increase in percentage of iron in ‘fufu’ and ‘gari; products microbially produced from Suleja cassava samples are prensented in Figure 4.52. The highest percentage increase was observed in ‘fufu’ produced from‘Kpace Bokun’ through *S. cerevisae* fermentation (47.48%) and ‘fufu’ from TME419 inoculated with *L. bulgaricus (*44.12%), while the lowest values was recorded in ’Karimugi’s ‘gari’ produced through *S. cerevisae* fermentation (1.45%) and ‘fufu’ manufactured from ’Kpace Dzuru’ through *L. bulgaricus* fermentation (1.28%). Considering the iron content as presented in Appendices XX, XXI and XXII, Duncan test indicated that there

were no significant differences ($P > 0.05$) between the values of iron in the microbially fermented products compared to the others (the 'lafun' products and naturally produced 'gari' and 'fufu' products).

Result of levels of increase in percentage of iron of 'fufu' and 'gari; products microbially produced from Kontagora cassava samples is presented in Figure 4.53. It was observed from the results that there was no significant difference among the values obtained for the products from L30572, 'Dam Warri', and 'Kpace Dzuru' varieties of the two fermentations. This showed that the increase in the percentage of iron was higher in thse varieties. There was a significant difference ($P < 0.05$) between the microbially inoculated products and the naturally treated products from 'Karimugi', TMS92/0326 and 'Kpace Dzuru' varieties (Appendices XXIII, XXIV and XXV).

Results of increase in percentage of iron in'fufu' and 'gari; products microbially produced from Bida cassava samples are presented in Figure 4.55. The level of percentage increase of iron in the products determined showed no significant difference. The level of iron ranged from 0.58% to 46.82% in *S. cerevisae*-fermented produced from 'Baba Iya' and *S. cerevisae*-inoculated 'fufu' obtained from L30572 respectively. Considering the iron content as presented in Appendices XXVI, XXVII and XXVIII, it was observed that there were no significant differences ($P > 0.05$) between the values of microbially fermented products and the others (the 'lafun' products and naturally produced 'gari' and 'fufu' products), except for the 'dan warri' variety which showed significant differences ($P > 0.05$) between the values .

5.3.7 Effect of inoculation on the level of phosphorus cootent in the products

Figure 4.55 represents the result of level of increase in percentage of phosphorus in cassava-based products - 'fufu'and 'gari'- produced from Suleja cassava samples through microbial fermentation. There were significant increase in 'fufu' (25.98%) from 'Karimugi' cultivar through *L. bulgaricus* fermentation, 'fufu' (23.99%) from 'Karimugi' of *S. cerevisae* fermentation and 'fufu' products (21.33% and 25.98%) from 'Kpace Dzuru through *L. bulgaricus* and *S. cerevisae* fermentations respectively compared to the uninoculated couterparts ($P < 0.05$). Cultivars of L30572 and 'Baba iya' were observed to be very low in phosphorus content in both 'gari' and 'fufu' products. Moreover, there was significant differences between the microbial fermented products and the natural fermented products produced from 'Karimugi', (25.98%) 'Wahabi' (15.06%) and 'Kpace Dzuru' (25.98%) varieties.

Figure 4.56 represent the results of level of increase in percentage of phosphorus in cassava-based products - 'fufu'and 'gari'- produced from Kontagora cassava samples through microbial fermentation. There were significant increase in in the phosphorus in 'gari' (21.56%) made from 'Karimugi' cultivar through *S. crevisae* fermentation, 'gari' (26.88%) produced from TMS92/0326, 'fufu' (25.98%) from TME419 and 'fufu' (25.98%) obtained from'baba iya' through the action of *L. bulgaricus.* Moreover, there were no significant differences ($P > 0.05$) in the microbial fermented products and the natural fermented products produced from most varieties (Appendices XXIII, XXIV and XXV).

Figure 4.57 presents the result of percentage increase of phosphorus in the cassava-based products - 'fufu'and 'gari'- produced from Bida cassava samples through microbial fermentation. There was a significant increase in the amount of phosphorus for 'fufu' (49.32%) from 'Kpace

Bokun' cultivar through *S. cerevisae* fermentation compared to the rest of the products. The remaining cultivars were observed to be very low in percentage phosphorus content elevation for both the 'gari' and 'fufu' products. Moreover, there were no significant differences ($P > 0.05$) between the microbial fermented products and the natural fermented products produced from 'karimugi', 'wahabi'and 'kpace dzuru' varieties.

5.4 Soil Composition of the Areas Where Cassava Samples Were Planted

5.4.1 Physico-chemical contents of soil samples of Kontagora town

Table 4.1 presents the result of the physico-chemical analysis of the soil samples of Kontagora town where the cassava samples were grown. The soil samples (topsoil and subsoil) covered Wushshi, Bunigi, Kawo and Maito sites. The parameters considered in this study included copper, iron, magnesium, sodium, potssium, texture (silt, sand and clay) organic carbon, organic matter and pH. The results showed that the textural class of the soils was sandy loam except the subsoil samples from Wushishi and Bunigi which was of loamy sand textural class. The reason for this similarity could be as a result of the fact that the two sampling sites were on the same geographical terrain. The pH values obtained for all the soil samples were not significantly different ($P > 0.05$), values ranged from 6.00 ± 0.15 to 6.30 ± 0.08 (Table 4.1). This indicated that the soil samples are fairly acidic. The values agreed with the preferred level pH ($CaCl_2$): 6.0 to 6.5 reported by Tom (1998) as suitable for most agricultural and horticultural purposes.

Furthermore, the texture of the soil samples revealed that sand composition recorded the highest values. Apart from the soil samples obtained from Kawo, sand compositions of the samples of the other three sampling sites recorded higher values for the subsoil samples than the topsoil

samples. In the same vein, there were no clear trends in the level of silt and clay contents for both the topsoil and subsoil samples of the four sampling points. The values for sand, silt and clay contents ranged from 70.42 ± 1.31% to 81.57 ± 0.82%, 5.23±0.32% to 10.25±0.25% and 11.25 ± 0.21% to 22.23±0.43% respctively (Table 4.1).

The organic carbon and oganic matter contents of the soil samples had the highest value of organic carbon being 2666.65 ± 6.65 $mgkg^{-1}$ and the least being 1666.63 ± 6.18 $mgkg^{-1}$. There was an appreciable difference between the values obtained for the topsoil and subsoil samples. Similarly, the highest and the least values for the organic matter content were 2149.94 ± 7.78 mg/kg and 4586.64 ± 6.87 $mgkg^{-1}$ respectively. There was also a significant difference in the organic matter values recorded for the topsoil compared to subsoil samples.

Of the elements (iron, magnesium, sodium, potassium, calcium, copper and phosphorus) determined, those that were of low compositions were the copper and available phosphorus. Considering the iron contents, it was observed that subsoil samples recorded higher values than the values obtained for the topsoil samples. This could be attributed to the leaching action of the minerals into the soil. The range of the values was 86 - 277 $mgkg^{-1}$ for iron content reported by Okeyode and Rufai (2011). This is lower than the range of values (894.57 ± 2.30 - 2484.37 ± 2.31 $mgkg^{-1}$) obtaained for this study.

The levels of copper, based on the results, were significantly low when compared with the values obtained for other minerals evaluated (Table 4.1). The highest value of 105.33 ± 2.43 $mgkg^{-1}$ was obtained for Bunigi subsoil (BNGSS), while the lowest value of 45.36 ± 0.97 $mgkg^{-1}$ 1was recorded for Kawo topsoil (KWOTS). For copper, the preferred or recommended value for good soil ranged between 2 mg/kg and 50 mg/kg (Tom, 1998). The range of the values obtained

for this findings was similar to the range of value (96.4 $mgkg^{-1}$ and 9.1 $mgkg^{-1}$) reported by Bradford *et al* (1996). Similarly, with the exception of soil samples from Wushishi, the values of copper contents of the subsoil samples were observed to be higher than the values for the topsoil samples possibly due to leaching.

Moreover, sodium contents of the soil samples showed similar trends with the results of iron contents. Subsoil samples contained higher values than the values for the topsoil samples as a result of leaching action advanced earlier for iron and copper contents. For the results of potassium, calcium, magnesium and available phosphorus, there was no clear relationship betweem the values of the minerals in the subsoil and those in topsoil samples. The range of values for potassium (187.17±1.08 to 2433.18±2.48 $mgkg^{-1}$), magnesium (800.09±9.08 to 2080.45±5.58 $mgkg^{-1}$), calcium (1200.56±6.68 to 2000.54±5.58 $mgkg^{-1}$) and available phosphorus (597.08±8.68 to698.34±4.82 $mgkg^{-1}$) were higher than the range of values (187–292 mg kg-1 for copper) reported by Gediminas and Rasa (2010). The usual trend, however, of low values of calcium, magnesium, potassium and available phosphorus in Kontagora and Bida samples was not different with the values obtained in Suleja samples.

5.4.2 Physico-chemical contents of of soil samples of Suleja town

The result of physico-chemical parametres of soil samples from Suleja town on which the cassava samples were cultivated is presented in Table 4.29. The results revealed that majority of the soil samples were of sandy loam tectural class, while topsoil samples from Kpasson and Gwam as well as the subsoil samples from Jita were of loamy sand tectural class. Considering the pH of the soil samples, it was observed that there was no significant difference amongst the values obtained, which confirmed the oil samples as moderately acidic (Table 4.2).

In addition, there were significant differences in the textural constituents of the soil samples, sand composition being the highest followed by the clay and then lastly the silt content. The highest values of 83.58 ± 1.81%, 11.22 ± 0.57% and 20.27 ± 0.45% were recorded for sand, silt and clay compositions respectively. Also, the values obtained for Suleja town were not significantly different from the values obtained for Kontagora town.

Furthermore, organic matter contents of the soils collected from Suleja town had it that topsoil samples had higher organic matter contents than the subsoil samples. This could be due to decomposed materials embedded in the topsoil. However, there was no clear relationship between the organic carbon contents in the subsoil and those of the topsoil samples. The highest value of organic carbon content was recorded as 2749.90 ± 4.91 $mgkg^{-1}$ and the least was 833.63±1.80 $mgkg^{-1}$.

Considering the elemental compositions, iron and copper contents showed clear variation between the values for topsoil and subsoil samples. Subsoil samples recorded higher values of copper abd iron than the values obtained for the topsoil samples. The highest value of 4404.23 ± 4.00 $mgkg^{-1}$ for the iron contents was obtained for Kpasson subsoil (KSOSS), while Jita subsoil (JTASS) had the lowest value of 3474.86 ± 5.77 $mgkg^{-1}$. These values conformed to the values reported by Temine *et al*. (2007).

As for the copper contents, the mean values obtained were 30.31 ± 1.15 $mgkg^{-1}$ and 210.43 ± 4.32$mgkg^{-1}$ as lowest and highest values respectively. These values were significantly different from the values (5.4191 to 0.1645 $mgkg^{-1}$) reported by Okeyode and Rufai (2011) for the soil of Suleja town. However, there were significant differences between the values realized for

Kontagora and Sulejs samples. Soil samples from Suleja town had higher iron and copper contents than the samples from Kontagora town.

Moreover, there were no obvious relationship amongst calcium, sodium, potassium, magnesium and available phosphorus contents in the topsoil and subsoil samples. It appeared from the results that there were no appreciable differences between the results of Suleja and the ones obtained from Kontagora samples.

5.4.3 Physico-chemical contents of soil samples of Bida town

Table 4.3 represents the result of the level of physico-chemical compositions of soil samples obtained from Bida sampling area, where the cassava samples were planted and cultivated. From the results, the range of the soil pH (6.00 and 6.30) remained the same as obtained for the two other towns, indicating that the measure of acidity or alkalinity of the samples of the three towns was not significantly different. The range of values for iron content was 204.27 ± 1.15 $mgkg^{-1}$ for Kuchita subsoil (KCTSS) and 366.17 ± 4.13 $mgkg^{-1}$ for Kuchita topsoil (KCTTS). These values were similar to the values obtained from the findings of Temine *et al*. (2007), and slightly different from the results of Okeyode and Rufai (2011). The level of copper contents was highest in KCTSS (90.67±1.54 $mgkg^{-1}$) and lowest in Masaga topsoil (MSGTS) (15.23 ± 0.57 $mgkg^{-1}$). These values were significantly lower than the values obtained for Kontagora (45.13±0.65 - 387.29 ± 3.23 $mgkg^{-1}$) and Suleja samples (30.31 ± 1.15 - 210.43 ± 4.32 $mgkg^{-1}$).

The organic carbon and organic matter contents of the Bida soil sample were significantly high with values ranged from 916.63 ± 2.81 $mgkg^{-1}$ to 3166.64 ± 8.88 $mgkg^{-1}$ for organic carbon and from 1576.43 ± 5.48 $mgkg^{-1}$ and 5446.64 ± 9.99 $mgkg^{-1}$ for organic matter respectively. Also,

there was a discernable trend between the values for the subsoil and topsoil samples. Comparing these values with the the values of findings of Bradford *et al*. (1996), it was observed that the values were not significantly different. As for the sodium contents, its highest value was found in Batavovogi subsoil (BTVSS) (384.62 ± 4.41mgkg^{-1}), which was also the highest of all the values of the three sampling towns. The values obtained in these results for Bida town were lower than the values reported by Bradford *et al*. (1996), which had values as high as 19540 mgkg^{-1} in the soil determined.

Furthemore, there were no significant differences between the values recorded for potassium contents of all the three towns investigated. But the values were lower than the values reported by Temine et al. (2007). Also in most cases, potassium contents of subsoil samples were greater than the topsoil samples, most probably as a result of leaching of the mineral into the soil. A range of values of 800.21 ± 6.85 mgkg^{-1} and 1360.43 ± 3.33 mgkg^{-1} was recoded as the levels of magnesium composition. This range of values conformed to to the values obtained by the findings of Gediminas and Rasa (2010). Also, these values were similar to the values recorded for both Kontagora and Suleja samples. The level of calcium content was highest in BTVSS (2440.22 ± 4.35 mgkg^{-1}) and lowest in KCTTS (1280.23 ± 7.78 mgkg^{-1}). Available phosphorus composition was observed to be low compared to other minerals determined. This indicated that the soil requires the addition of phosphorus as a supplement being a macroelement through application of inorganic or organic fertizers.

Generally, it has been observed that the values minerals obtained for the cassava products treated microbially were higher than the values recorded for the soil samples on which the cassava samples were planted. This was accounted for by the fact that there occured a bioaccumulation

of these minerals in the body tissues of the microorganisms as they grow (Challaraj *et al*., 2011 and Anita., 1996). The second likely source of metals getting into the products could be as a result of metallic knife used for the peeling of the cassava root tubers prior to fermentation. Another source may probably be due to the fact that a metallic frying pan was used for processing the pressed and sieved pulp into gari and some of those metals may have leached into the gari.

CHAPTER 6

6.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

Cassava pulp of nine varieties were subjected to microbial fermentation prior to processing the pulp traditionally to 'gari' and 'fufu' products using *Saccharomyces cerevisea* and *Lactobacillus bulcaricus* as fermenting organisms. 'Lafun' products were processed directly from the cassava tubers without fermentation; 'gari' and 'fufu' products processed through natural fermentation were also produced from these varieties of cassava. Subsequetly, appropriate samplings and the collection of the cassava samples as well as the sioil samples of the areas where the cassava varieties were planted were carried out.

Analyses carried out on these samples revealed that microbial fermentation caused increaase in protein (91%), fat (98%), iron (68%), zinc (53%), calcium (35%), potassium (45%), sodium (48%), magnesium (55%) and phosphorus (%) contents while it caused decrease in crude fibre (85%), carbohydrate (10%), cyanide (86%), tannins (73%), oxalate (61%), phytate (72%) and saponins (92%). There were also differences between the values obtained for microbial fermented products and the natural natural fermented products. Also, significant differences were observed between the compositions of 'lafun' products and the compositions of fermented products. From these results it could be inferred that microbial fermentation had proved useful in enriching the nutritive values of cassava products, by increasing the nutritional contents and reducing the anti-nutritional factors.

6.2 Conclusions

(i) The inoculation of cassava pulp with *S. cerevisae* and *L. bulgaricus* during fermentation enhanced the nutritional status of the products obtained.

(ii) The nature of organism used for fermentation and the type of soil on which the cassava samples were planted significantly affected the quality of the products. For example, most elements analysed in soil samples of Bida town had higher values, which could have accounted for the corresponding high values of nutritional compositon bof the soil samples.

(iii) *S. cerevisae* had greater ability to a large extent (about 40%) to nutritionally enrich the cassava products than the *L. bulgaricus*.

(iv)) Most 'fufu' products were more nutritionally improved by the fermentation with the two organisms than the 'gari' products.

(v) There was no clear trend regarding varietal compositions between the improved and local varieties.

(vi) There was also no clear trend when considering the geographical diferences in terms of the three towns investgated.

6.3 Recommendations

(i) The governments at local levels should carry out enlightenment campaigns to the rural populace on the benefits of inoculation of cassava products in order to boost consumption of protein, and prevent malnutrition associated with constant dependence on cassava based foods. Siince the inoculants (the organisms) are chaep and easily accessible, they can be delievered to the farmers as ice packs as the immunisation vaccines through the bodies like the Cassva Growers Association of Nigeria.

(ii) The findings of this research can be applied in producing other foods manufactured through fermentation like bread, beer, soy sauce, alcohols, glycerol and lactic acid to improve thier nutrient quality.

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Appendix I: List of chemicals/reagents and equipments

Chemicals

Ammonia

Ammonium hydroxide

Ammonium acetate (70 cm^3 of ammonia solution and 57 cm^3 of acetic acid, 99.5%)

Ammonium molybdate tetrahydrate

Ammonium metavanadate (0.25 g)

Ammonium iron (II) tetraoxosulphate (VI) (0.2 M)

Ammonium molybdate

barium diphenylamine sulphonate (0.3 g)

Barium chloride (5 g)

Boric acid (2%)

Bromocrysol (0.2%)

Cadmium metal (1.00 g)

Calcium chride (0.01 M)

Calcium trioxocarbonate (IV) (2.4973 g)

Copper (II) tetraoxosulphate (VI) tetrahydrate (3.963 g)

Ethanoic acid

Ethanol

Hydrochloric acid (1 $moldm^{-3}$ and 0.014 $moldm^{-3}$)

molybdovanadate reagent (5.0 g of ammonium molybdate tetrahydrate in 50 cm^3 of hot water)

Magnesium chloride hexahydrte (3.9160 g)

Manganese (II) chloride (3.6077g)

Mercuric oxide (0.07 g)

Methyl red (0.1%)

O-phenathroline

Perchloric acid (70%)

Petroleum ether

picric acid (0.500 g)

Potassium chloride (1.9103 g)

Potassium cyanide (0.004 g of dry KCN in 100 cm^3 of distilled water)

Potassium heptaoxodichromate (VI) (1 M)

Potassium hydrogen tetraoxophosphate (V) (0.1220 g)

Potassium tetraoxomanganate (VII) (0.025 $moldm^{-3}$)

Potassium tetraoxosulphate (VI) (1 g)

Sodium chloride (2.5435 g and 0.7 $moldm^{-3}$)

Na_2EDTA (0.11$moldm^{-3}$)

Sodium hydroxide (0.313 $moldm^{-3}$,40% and 0.1 $moldm^{-3}$)

Sodium phosphate

Sodium sulphide (4%)

Sodium trioxocarbonate (IV) (6.25 g)

Sodium trioxosulphate (IV)

Sodium hydrogen trioxosulphate (IV)

sulphonic acid reagent (0.16 g 1- amino-2-naphthol-4-suphonic acid, 1.92 g Na_2SO_3 and 9.60 g $NaHSO_3$)

Tetraoxosulphate (VI) acid (concentrated and 0.1275 $moldm^{-3}$)

Tetraoxophosphate (V) acid

Tin (II) chloride

Trioxonitrate (V) acid (concentrated)

Zinc oxide (1.2450 g)

Equipments

Ccolorimetrer.

flame photometer (Model: JENWAY PFP 7)

Microwave oven (Uniscope SM9053)

Muffle furnace (Gallenkamp Ltd)

Spectrophotometer (model JENWAY 6310)

Atomic Absorption Spectophotometre (Model: AA 240 FF).

Appendix II: Proximate composition of microbial fermented cassava products of TME419, KG and TMS92/0326 varieties (% dry weight) of Kontagora samples

Variety	product	Parameters						
		crude protein	crude fiber	crude fat	moisture	ash	TDM	carbohydrate
TME419	Gari	6.95±0.04^{f}	3.54±0.07^{c}	3.61±0.04^{c}	5.68±0.03^{c}	1.95±0.06^{ab}	94.32±0.03^{b}	86.91±0.04^{a}
	Fufu	3.22±0.03^{ab}	2.63±0.14^{b}	1.12±0.03^{a}	5.78±0.08^{c}	0.78±0.03^{a}	94.21±0.08^{b}	95.38± 0.02^{b}
	Lafun	2.13±0.15^{b}	2.98±0.06^{b}	1.24±0.19^{f}	3.35±0.02^{a}	4.06±0.04^{ab}	96.65±0.01^{b}	79.19± 0.01^{a}
LITME419	Gari	9.09±0.09^{i}	3.49±0.11^{c}	4.86±0.10^{e}	5.56±0.05^{c}	2.17±0.03^{b}	94.44±0.05^{b}	82.06±0.04^{a}
	Fufu	4.82±0.02^{b}	1.37±0.05^{a}	3.41±0.03^{c}	6.54±0.06^{d}	0.34±0.05^{a}	93.46±0.03b	90.71±0.01^{a}
SITME419	Gari	9.95±0,07^{i}	3.44±0.11^{c}	5.32±0.12^{e}	4.95±0.21^{c}	1.38±0.01^{a}	95.05±0.04^{b}	81.60±0.02^{a}
	Fufu	4.92±0.23^{c}	2.24±0.32^{b}	1.46±0.06^{a}	5.12±0.35^{d}	2.17±0.03^{b}	94.88±0.35^{b}	90.53±0.02^{a}
KG	Gari	8.02±O.37^{h}	4.47±0.82^{d}	4.25±0.25^{d}	5.02±0.06^{d}	2.73±1.00^{b}	94.98±0.06^{b}	81.95±0.03^{a}
	Fufu	4.62±0.04^{b}	2.28±0.20^{b}	0.24±0.13^{a}	5.84±0.06^{d}	0.60±0.01^{a}	94.16±0.05^{b}	93.61±0.03^{b}
	Lafun	3.14±1.00^{ab}	2.55±0.23^{b}	5.26±0.06^{e}	3.93±0.07^{a}	3.30±0.15^{c}	96.07±0.07^{b}	88.3±0.03^{a}
LIKG	Gari	8.85±0.04^{h}	4.31±0.21^{d}	5.27±0.13^{e}	5.91±1.11^{d}	2.80±0.22^{b}	94.09±1.11^{b}	80.46±0.02^{a}
	Fufu	6.58±0.03^{f}	2.09±0.44^{b}	0.81±0.04^{a}	5.73±0.10^{c}	2.16±0.04^{b}	94.27±0.08^{b}	89.62±0.02^{a}
SIKG	Fufu	4.97±0.04^{c}	2.00±0.09^{b}	1.05±0.22^{a}	6.18±0.11^{d}	1.98±0.18^{ab}	93.82±0.09^{b}	91.80±0.03^{a}
	gari	9.06±0.08^{i}	3.74±0.35^{c}	5.23±0.04^{e}	5.68±0.05^{c}	1.80±0.03^{ab}	94.32±0.04^{b}	82.80±0.30^{a}
TMS92/0326	Gari	2.74±0.08^{a}	4.18±0.18^{d}	5.37±0.11^{e}	7.55±0.02^{e}	1.63±0.03^{ab}	92.45±0.02^{b}	88.67±0.02^{a}
	Lafun	2.82±0.09^{a}	1.80±0.16^{b}	3.72±0.12^{g}	3.15±0.03^{a}	5.20±0.02^{j}	96.85±0.02^{b}	86.12±0.03^{a}
	Fufu	3.78±0.07^{ab}	1.70±0.50^{a}	7.42±0.19^{h}	7.07±0.04^{e}	0.62±0.04^{a}	92.93±0.04^{b}	91.96±0.01^{a}
SITMS92/0326	Gari	7.74±0.12^{h}	3.92±0.09^{d}	5.73±0.13^{d}	7.00±0.03^{e}	1.70±0.13^{ab}	93.00±0.03^{b}	83.76±0.03^{a}
	Fufu	4.21±0.12^{b}	0.87±0.13^{c}	7.55±0.12^{h}	7.32±0.04^{e}	2.80±0.22^{j}	92.68±1.12^{b}	87.58±0.03^{a}
LITMS92/0326	Gari	5.80±0.08^{d}	4.00±0.05^{d}	4.90±0.08^{e}	7.80±0.04^{e}	2.17±0.03^{d}	92.62±0.04^{b}	84.19±0.01^{a}
	Fufu	4.01±0.05^{b}	1.38±0.06^{a}	7.68±0.22^{h}	7.88±0.04^{e}	1.10±0.02^{ab}	92.12±0.10^{b}	88.47±0.02^{a}

Means with the same superscripts within a column are not significantly different ($p > 0.05$)

TME419 = Improved vaiety, SITME419 = *S. cerevisea* fermented, KG = Karimugi, LITME419 = *L. bulgaricus* fermented, LIKG = *L. bulgaricus* fermented, LITMS92/0326 = *L. bulgaricus* fermented, SITMS92/0326 = *S. cerevisea* fermented SIKG = *S. cerevisea* fermented, TMS92/0326= Improved variety

Appendix III: Proximate composition of microbially fermented cassava products of KB, BI and W varieties (% dry weight) of Kontagora samples

Variety	product	Parameters						
		crude protein	crude fiber	crude fat	moisture	ash	TDM	carbohydrate
KB	Gari	5.66±0.91^{d}	3.28±0.10^{c}	1.58±0.08^{d}	6.39±0.02^{d}	2.68±0.10^{i}	93.61±0.02^{b}	83.12 ± 0.02^{a}
	Lafun	4.62±0.91^{b}	1.84±0.13^{a}	3.43±0.04^{c}	3.41±0.03^{a}	5.01±0.04^{ij}	97.59±0.12^{b}	85.52 ± 0.02^{a}
	Fufu	5.98±0.91^{d}	1.12±0.30^{a}	1.20±0.06^{a}	5.47±0.08^{c}	1.32±0.03^{a}	94.53±0.08^{b}	91.01 ± 0.01^{a}
LIKB	Gari	7.41±0.91^{h}	3.12±0.30^{c}	5.94±0.34^{e}	6.57±0.07^{d}	2.36±0.05^{h}	93.43±0.07^{b}	83.09 ± 0.01^{a}
	Fufu	8.33±0.12^{i}	1.02±0.10^{a}	2.22±0.42^{b}	5.54±0.12^{c}	1.64±0.05^{ab}	94.46±0.23^{b}	88.80 ± 0.02^{a}
SIKB	Gari	7.01±0.38^{h}	2.98±0.10^{c}	4.64±1.61^{e}	7.45±0.23^{e}	2.16±0.04^{f}	92.55±0.51^{b}	89.71 ± 0.01^{a}
	Fufu	7.92±0.06^{h}	0.97±0.09^{a}	2.48±0.04^{b}	5.75±0.06^{d}	2.80±0.22^{j}	94.15±0.04^{b}	84.01 ± 0.01^{a}
BI	Gari	4.99±0.09^{c}	3.30±0.15^{c}	3.87±0.07^{c}	4.52±0.04^{b}	2.24±0.06^{g}	95.48±0.03^{b}	82.26 ± 0.02^{a}
	Fufu	3.98±0.07^{ab}	0.90±0.50^{a}	0.14±0.01^{a}	2.61±0.10^{a}	1.22±0.03^{ab}	97.39±0.09^{b}	95.2l ± 0.02^{b}
	Lafun	2.77±0.10^{d}	9.59±0.41^{h}	2.26±0.06^{b}	4.12±0.09^{b}	7.13±0.02^{j}	95.88±0.02^{b}	71.18 ± 0.04^{a}
LIBI	Gari	5.98±0.08^{d}	3.01±0.05^{c}	3.94±0.06^{d}	4.95±0.21^{c}	1.38±0.01^{a}	95.05±0.04^{b}	88.28 ± 0.03^{a}
	Fufu	4.16±0.10^{b}	1.00±0.13^{a}	2.92±0.03^{c}	5.12±0.35^{c}	2.16±0.04^{f}	97.84±0.35^{b}	90.93 ± 0.03^{a}
SIBI	Gari	5.79±0.08^{d}	0.86.±0.24^{a}	5.90±0.08^{e}	4.81±0.02^{c}	1.37±0.06^{ab}	95.19±0.02^{b}	88.22 ± 0.02^{a}
	Fufu	7.33±0.12^{h}	0.89±0.30^{a}	2.22±0.42^{b}	4.94±0.12^{c}	2.56±0.04^{f}	95.06±1.12^{b}	87.99 ± 0.04^{a}
W	Lafun	2.17±0.05^{b}	6.17±0.37^{g}	2.15±0.03^{d}	3.87±0.02^{a}	3.49±0.02^{j}	96.13±0.01^{b}	81.32 ± 0.56^{a}
	Gari	3.02±O.37^{ab}	5.74±0.35^{e}	4.25±0.02^{e}	5.70±0.08^{c}	1.78±0.03^{a}	94.30±0.08^{b}	93.08 ± 0.01^{b}
	Fufu	4.62±0.04^{b}	1.75±0.19^{a}	2.85±0.07^{c}	5.18±0.13^{c}	1.12±0.05^{ab}	94.92±0.13^{b}	92.38 ± 0.01^{b}
SIW	Gari	8.33±0.12^{i}	4.98±0.21^{e}	6.94±0.23^{g}	4.65±0.08^{c}	0.88±0.03^{a}	95.35±0.08^{b}	85.08 ± 0.03^{a}
	Fufu	3.68±0.03^{ab}	1.64±0.13^{a}	1.17±0.11^{a}	5.75±0.22^{d}	0.34±0.06^{a}	94.25±38.57^{b}	92.16 ± 0.03^{b}
LIW	Gari	6.10±0.10^{e}	5.58±0.35^{e}	4.99±0.07^{d}	5.96±0.08^{d}	1.70±0.02^{ab}	94.04±0.01^{b}	83.89 ± 0.04^{a}
	Fufu	6.58±0.03^{f}	1.08±0.44^{a}	3.25±0.04^{a}	5.73±0.10^{cd}	2.16±0.04^{f}	94.27±0.08^{b}	90.89 ± 0.03^{a}

Means with the same superscripts within a column are not significantly different ($p > 0.05$)

BI = Baba Iya, LIBI = *L. bulgaricus* fermented, SIBI = *S. cerevisea* fermented,

W = Wahabi, LIW= *L. bulgaricus* fermented, SIW= *S. cerevisea* fermented,

B = Kpace Bokun, LIKB = *L. bulgaricus* fermented, SIKB = *S. cerevisea* fermented

Appendix IV: Proximate composition of microbially fermented cassava products of KD, DW and L30572 (% dry weight) of Kontagora samples

Variety	product	Parameters						
		crude protein	crude fiber	crude fat	Moisture	Ash	TDM	carbohydrate
KD	Lafun	0.89±0.04^{f}	1.68±0.01^{a}	1.62±0.37^{h}	3.58±0.08^{a}	2.13±0.04^{b}	96.42±0.21^{b}	81.81 ± 0.01^{a}
	Fufu	2.25±0.06^{a}	1.25±0.16^{a}	1.47±0.11^{a}	5.55±0.08^{c}	2.74±0.06^{b}	94.45±0.07^{b}	93.91 ± 0.04^{b}
	Gari	4.26±0.08^{b}	2.00±0.35^{b}	2.74±0.05^{b}	6.53±0.04^{d}	2.08±0.16^{b}	93.47±0.03^{b}	91.38 ± 0.02^{a}
LIKD	Gari	3.68±0.04^{ab}	2.60±0.15^{b}	3.60±0.14^{c}	7.30±0.12^{e}	1.65±0.07^{a}	92.70±1.80^{b}	91.19 ± 0.01^{a}
	Fufu	4.82±0.04^{b}	1.07±0.04^{a}	1.65±0.11^{a}	5.61±0.04^{c}	0.58±0.04^{a}	94.39±1.80^{b}	93.06 ± 0.04^{b}
SIKD	Fufu	4.87±0.04^{c}	1.15±0.09^{a}	1.58±0.22^{a}	6.58±0.11^{d}	1.98±0.18^{b}	93.42±0.09^{b}	92.71 ± 0.01^{b}
	Gari	9.46±0.08^{h}	2.44±0.35^{b}	4.23±0.04^{d}	6.68±0.05^{d}	1.80±0.03^{b}	93.32±0.04^{b}	83.60 ± 0.02^{a}
DW	Gari	3.77±1.00^{ab}	3.65±0.86^{d}	4.54±0.05^{d}	4.34±1.06^{b}	1.35±0.59^{a}	95.66±0.06^{b}	88.53 ± 0.02^{a}
	Lafun	2.02±1.95^{b}	1.28±0.40^{a}	6.65±0.56^{f}	3.36±1.45^{b}	1.78±0.82^{b}	95.64±1.45^{b}	89.95 ± 0.03^{a}
	Fufu	2.95±0.42^{a}	1.88±0.16^{b}	3.54±0.17^{c}	4.87±0.12^{b}	1.19±0.20^{a}	95.13±0.41^{b}	92.61 ± 0.03^{b}
LIDW	Gari	7.02±O.37^{g}	3.22±2.42^{c}	4.91±0.15^{e}	4.57±1.09^{b}	1.41±0.04^{a}	95.43±1.11^{b}	84.37 ± 0.03^{a}
	Fufu	3.65±0.42^{ab}	1.65±0.86^{a}	3.97±2.21^{d}	5.98±0.62^{d}	2.74±0.06^{b}	94.02±0.62^{b}	90.46 ± 0.02^{a}
SIDW	Gari	4.27±1.00^{b}	2.98±0.30b^{c}	4.66±0.06^{e}	4.63±1.10^{b}	2.08±0.16^{b}	95.47±1.11^{b}	87.62 ± 0.02^{a}
	Fufu	3.75±0.42^{ab}	1.71±0.16^{b}	3.83±2.21^{c}	4.98±0.42^{c}	2.47±0.05^{b}	95.02±0.62^{b}	90.80 ± 0.03^{a}
L30572	Gari	2.86±0.04^{a}	3.22±2.42^{c}	2.78±0.06^{b}	5.92±0.03^{d}	1.66±0.05^{b}	94.08±0.03^{b}	91.80 ± 0.30^{a}
	Lafun	3.61±0.06^{ab}	2.87±0.15^{b}	1.27±0.44^{i}	2.61±0.01^{a}	2.72±0.03^{b}	97.39±0.01^{b}	83.67 ± 0.02^{a}
	Fufu	2.56±0.04^{a}	3.01±0.22^{a}	3.32±0.09^{c}	5.55±0.06^{d}	1.13±0.06^{a}	94.45±0.06^{b}	92.12 ± 0.03^{b}
SIL30572	Gari	4.97±0.04^{b}	3.20±0.22^{c}	2.87±0.44^{c}	5.82±0.05^{d}	1.81±0.03^{b}	94.18±0.05^{b}	89.96 ± 0.01^{a}
	Fufu	4.82±0.02^{c}	1.17±1.12^{a}	3.45±0.09^{c}	5.75±0.08^{d}	0.50±0.36^{a}	94.25±0.01^{b}	91.76 ± 0.03^{a}
LIL30572	Fufu	3.80±0.04^{ab}	1.82±0.22^{c}	3.42±0.04^{c}	5.56±1.09^{d}	1.78±0.82^{a}	94.44±0.06^{b}	90.58 ± 0.03^{a}
	Gari	3.29±0.04^{ab}	1.58±1.10^{a}	2.98±0.05^{c}	6.00±0.03^{d}	1.19±0.20^{a}	94.00±0.05^{b}	92.19 ± 0.01^{b}

Means with the diferrent superscripts within a column are significantly different ($p < 0.05$)

KD = Kpace Dzuru, LIKD = *L. bulgaricus* fermented, SIKD = *S. cerevisea* fermented, DW= Dan Warri, LIL30572 = *L. bulgaricus* fermented LIDW = *L. bulgaricus* fermented, SIDW = *S. cerevisea* fermented L30572 = Improved vaiety SIL30572 = *S. cerevisea* fermented

Appendix V: Proximate composition of microbially fermented cassava products of TME419, KG and TMS92/0326 (% dry weight) of Bida samples

Variety	product	Parameters						
		crude protein	crude fiber	crude fat	moisture	Ash	TDM	Carbohyderate
TME419	Gari	4.26±0.08^{b}	2.16±0.20^{b}	3.61±0.04^{c}	8.41±0.05^{f}	1.63±0.04^{b}	91.59±0.05^{b}	90.91 ± 0.04^{b}
	Fufu	5.82±0.63^{d}	1.15±0.23^{a}	0.15±0.03^{a}	5.78±0.08^{d}	0.87±0.03^{a}	94.22±2.20^{b}	95.38 ± 0.02^{b}
	Lafun	3.15±0.09^{ab}	1.70±0.06^{ab}	5.82±0.12^{e}	3.35±0.02^{a}	3.56±0.04^{c}	96.65±0.02^{b}	87.19 ± 0.01^{a}
LITME419	Gari	5.49±0.04^{d}	2.04±0.08^{c}	9.40±0.73^{i}	5.78±0.04^{d}	1.73±0.04^{b}	94.22±0.04^{b}	82.06 ± 0.04^{a}
	Fufu	6.18±0.08^{e}	0.33±0.05^{a}	1.05±0.03^{a}	5.32±0.05^{c}	0.98±0.06^{a}	94.28±0.04^{b}	92.71 ± 0.01^{b}
SITME419	Gari	5.01±0.12^{d}	2.00±0.51^{c}	5.67±0.16^{e}	4.98±0.06^{c}	1.26±0,13^{ab}	95.02±0.05^{b}	86.60 ± 0.02^{a}
	Fufu	5.98±0.38^{d}	0.78±0.10^{a}	1.48±0.04^{a}	5.12±0.35^{c}	0.98±0.23^{a}	94.88±0.35^{b}	93.53 ± 0.02^{b}
KG	Gari	5.00±0.04^{d}	3.10±0.70^{c}	3.51±1.91^{c}	6.37±0.54^{d}	1.59±0.06^{b}	93.63±0.05^{b}	88.95 ± 0.03^{a}
	Fufu	4.20±0.06^{b}	1.94±0.17^{b}	5.36±0.09^{e}	5.84±0.06^{d}	1..02±0.25^{a}	94.16±0.85^{b}	89.61 ± 0.03^{a}
	Lafun	2.14±0.18^{a}	1.17±0.17^{a}	5.26±0.06^{e}	2.06±1.40^{a}	3.30±0.15^{c}	97.94±0.33^{b}	87.37 ± 0.03^{a}
LIKG	Gari	5.20±0.97^{d}	2.43±0.03^{b}	7.65±0.31^{h}	6.05±0.06^{d}	2.80±0.20^{c}	93.95±0.06^{b}	83.46 ± 0.02^{a}
	Fufu	4.97±0.07^{c}	1.89±0.42^{b}	6.72±0.05^{g}	5.73±0.10^{d}	1.52±0.03^{b}	94.27±0.08^{b}	89.62 ± 0.02^{a}
SIKG	Fufu	4.62±0.06^{c}	1.56±0.52^{a}	5.98±0.02^{f}	5.84±0.07^{d}	1.26±0,13^{a}	94.16±0.94^{b}	90.80 ± 0.03^{b}
	Gari	7.11±0,12^{h}	3.00±0.08^{c}	5.28±0.01^{e}	4.85±0.06^{b}	1.80±0.02^{b}	95.15±0.90^{b}	83.8 ±0.30^{a}
TMS92/0326	Gari	4.97±0.15^{c}	4.63±0.10^{e}	5.37±0.11^{e}	7.19±0.04^{e}	1.79±0.20^{b}	92.81±0.06^{b}	83.67 ± 0.02^{a}
	Fufu	3.78±0.08^{ab}	1.45±0.58^{a}	7.42±0.10^{h}	7.67±0.04^{e}	2.61±0.10^{c}	92.33±0.04^{b}	86.12±0.03a^{a}
	Lafun	2.82±0.09^{a}	1.80±0.16^{b}	7.32±0.20^{h}	3.15±0.03^{a}	5.20±0.02^{e}	96.85±0.04^{b}	84.96 ± 0.01^{a}
SITMS92/0326	Gari	8.81±1.40^{i}	2.84±0.12^{c}	5.43±0.18^{e}	3.62±0.04^{a}	1.88±0.29^{c}	96.38±0.22^{b}	83.76 ± 0.03^{a}
	Fufu	4.97±0.15^{c}	1.20±0.19^{a}	7.85±0.12^{h}	5.32±0.04^{c}	1.09±0.03^{a}	94.68±1.12^{b}	87.58 ± 0.03^{a}
LITMS92/0326	Gari	7.63±1.40^{h}	2.98±0.12^{c}	5.98±0.02^{f}	8.41±0.05^{f}	2.80±0.20^{c}	91.59±064^{b}	83.19 ± 0.01^{a}
	Fufu	3.36±0.06^{a}	1.38±0.05^{a}	7.02±1.80^{h}	6.42±0.05^{d}	1.10±0.01^{a}	93.58±0.22^{b}	87.47 ± 0.02^{a}

Means with the same superscript within a column are not significantly different ($p > 0.05$)

TME419 = Improved vaiety, SITME419 = *S. cerevisea* fermented, LITME419 = *L. bulgaricus* fermented, KG = Karimugi, LIKG = *L. bulgaricus* fermented, SIKG = *S. cerevisea* fermented, TMS92/0326= Improved vaiety, LITMS92/0326 = *L. bulgaricus* fermented, SITMS92/0326 = *S. cerevisea* fermented

Appendix VI: Proximate composition of microbially fermented cassava products of KB, BI and W varieties (% dry weight) of Bida samples

Variety	product	Parameters						
		crude protein	crude fiber	crude fat	Moisture	Ash	TDM	carbohyderate
KB	Gari	5.06±0.08^{d}	3.28±0.09^{c}	5.98±0.02^{f}	6.39±0.02^{d}	2.68±0.09^{c}	93.61±0.02^{b}	87.09 ± 0.02^{a}
	Lafun	1.40±0.57^{d}	2.90±0.13^{a}	3.72±0.06^{e}	4.49±0.62^{b}	3.87±1.79^{d}	95.51±1.62^{b}	82.52 ± 0.02^{a}
	Fufu	2.67±0.36^{a}	1.19±0.24^{a}	1.20±0.06^{a}	5.57±0.16^{c}	1.15±0.26^{a}	94.43±0.78^{b}	93.01 ± 0.01^{b}
LIKB	Gari	6.18±0.08^{e}	1.26±0.09^{a}	6.00±0.10^{f}	5.57±0.06^{c}	2.36±0.04^{b}	94.43±1.62^{b}	86.12 ± 0.01^{a}
	Fufu	2.98±0.04^{a}	1.16±0.07^{b}	2.74±0.10^{e}	6.05±0.06^{d}	1.64±0.04^{a}	93.95±0.82b	91.80 ± 0.02^{b}
SIKB	Gari	5.24±0.09^{d}	3.08±0.10^{c}	6.40±1.61^{f}	4.73±0.82^{b}	2.02±0.47^{b}	95.27±0.53^{b}	83.71 ± 0.01^{a}
	Fufu	3.78±0.08^{ab}	1.06±0.03^{b}	1.48±0.04^{a}	5.78±0.04^{d}	1.59±0.06^{b}	94.22±0.85^{b}	93.01 ± 0.01^{b}
BI	Gari	4.80±0.30^{c}	2.91±0.60^{c}	3.83±0.09^{c}	7.03±0.08^{e}	1.66±0.01^{b}	92.97±0.08^{b}	89.26 ± 0.02^{a}
	Lafun	2.39±0.57^{d}	7.12±3.73^{i}	0.98±0.42^{a}	2.61±0.10^{a}	7.13±0.02^{g}	97.39±0.10^{b}	75.2l ± 0.02^{a}
	Fufu	3.71±0.03^{ab}	1.55±0.07^{a}	0.33±0.28^{a}	4.12±0.09^{b}	1.28±0.02^{c}	95.88±1.94^{b}	86.18 ± 0.04^{a}
LIBI	Gari	5.05±0.06^{d}	2.71±0.05^{b}	3.98±0.06^{c}	6.74±1.52^{e}	2.45±0.21^{b}	93.26±1.52^{b}	87.28 ± 0.03^{a}
	Fufu	4.16±0.10^{b}	1.35±0.33^{a}	2.92±0.03^{b}	6.74±1.52^{e}	0.81±0.03^{a}	93.26±1.52^{b}	93.93 ± 0.03^{b}
SIBI	Gari	5.79±0.04^{d}	1.28±0,22^{a}	6.85±0.48^{g}	4.82±0.02^{b}	1.39±0.04^{a}	95.18±0.02^{b}	88.22 ± 0.02^{a}
	Fufu	3.98±0.08^{ab}	1.20±0.03^{a}	2.41±0.04^{b}	5.78±0.04^{d}	1.59±0.06^{b}	94.22±0.85^{b}	91.99 ± 0.04^{b}
W	Gari	1.21±0.02^{a}	3.10±0.86^{c}	6.94±0.21^{g}	4.34±0.03^{b}	2.67±0.04^{c}	95.66±0.03^{b}	87.32 ± 0.56^{a}
	Lafun	3.10±0.10^{b}	6.10±3.12^{g}	1.93±0.42^{b}	3.87±0.02^{a}	3.48±0.05^{c}	96.13±0.02^{b}	81.91 ± 0.01^{a}
	Fufu	3.17±0.03^{ab}	2.79±0.18^{b}	2.47±1.15^{ab}	5.18±0.13^{c}	0.79±0.50^{a}	94.82±0.13^{b}	92.16 ± 0.01^{b}
SIW	Gari	3.74±0.08^{ab}	2.71±0.05^{b}	6.99±0.02^{f}	4.82±0.02^{c}	1.65±0.17^{b}	95.18±0.03^{b}	86.08 ± 0.03^{a}
	Fufu	3.68±0.03^{ab}	2.28±0.05^{b}	3.08±0.25^{c}	5.51±0.39^{c}	0.58±0.37^{a}	94.49±38.57^{a}	92.38 ± 0.03^{b}
LIW	Gari	6.10±0.09e	3.11±0.05^{c}	7.11±0.10^{h}	6.44±0.08^{d}	1.70±0.01^{b}	93.56±0.08^{b}	81.89 ± 0.04^{a}
	Fufu	4.71±0.08^{c}	1.71±0.05^{b}	3.40±0.25^{c}	6.31±0.02^{d}	1.07±0.02^{a}	93.69±0.08^{b}	90.89 ± 0.03^{b}

Means with the same superscript letters within a column are not significantly different ($p < 0.05$)

BI = Baba Iya, LIBI = *L. bulgaricus* fermented, SIBI = *S. cerevisea* fermented, W = Wahabi, LIW= *L. bulgaricus* fermented, SIW= *S. cerevisea* fermented, B = Kpace Bokun, LIKB = *L. bulgaricus* fermented, SIKB = *S. cerevisea* fermented

Appendix VII: Proximate composition of microbial fermented cassava products of KD, DW and L30572 varieties (% dry weight) of Bida samples

Variety	Product	Parameters						
		crude protein	crude fiber	crude fat	Moisture	Ash	TDM	carbohyderate
KD	Gari	5.17±1.32^{d}	2.09±0.11^{b}	3.72±0.15^{c}	7.81±0.03^{e}	1.40±0.04^{a}	92.19±0.27^{b}	89.81 ± 0.01^{a}
	Lafun	2.79±1.65^{a}	0.95±0.41^{a}	2.93±1.07^{a}	7.58±0.08^{e}	2.13±0.04^{b}	92.42±0.02^{b}	86.91 ± 0.04^{a}
	Fufu	2.42±0.25^{a}	1.25±0.14^{a}	5.73±0.06^{e}	5.55±0.08^{c}	1.49±0.03^{a}	94.45±0.13^{b}	91.38 ± 0.02^{b}
LIKD	Gari	6.68±0.03^{f}	1.98±0.35^{b}	5.36±5.15^{e}	7.01±1.94^{e}	1.87±0.34^{b}	92.99±1.94^{b}	84.19 ± 0.01^{a}
	Fufu	4.73±0.06^{c}	1.09±0.57^{a}	6.35±0.16^{f}	4.99±0.10^{c}	0.58±0.04^{a}	95.11±0.02^{b}	90.06 ± 0.04^{b}
SIKD	Fufu	4.62±0.06^{c}	1.08±0.52^{a}	5.98±0.02^{f}	5.84±0.07^{d}	2.67±0.04^{c}	94.16±0.94^{b}	89.71 ± 0.01^{a}
	Gari	7.11±0,12^{h}	1.97±0.08^{b}	4.28±0.01^{d}	4.85±0.06^{c}	1.80±0.02^{b}	95.15±0.90^{b}	90.60 ± 0.02^{b}
DW	Gari	4.50±1.38^{c}	3.44±0.85^{c}	3.95±0.73^{c}	6.10±0.91^{d}	1.99±0.03^{b}	93.90±1.38^{b}	86.53 ± 0.02^{a}
	Lafun	2.47±1.70^{a}	1.22±0.38^{a}	2.65±0.58^{a}	4.07±1.21^{b}	1.78±0.72^{b}	95.93±0.93^{b}	89.95 ± 0.03^{a}
	Fufu	2.80±1.34^{a}	1.78±0.35^{b}	3.45±0.25^{c}	5.17±0.62^{c}	1.04±0.84^{a}	94.83±0.67^{b}	91.61 ± 0.03^{b}
LIDW	Gari	5.06±1.31^{d}	2.14±0.09^{b}	4.41±0.15^{d}	4.89±1.26^{b}	1.37±0.08^{a}	95.11±0.06^{b}	87.37 ± 0.03^{a}
	Fufu	3.35±1.70^{ab}	0.85±0.55^{a}	3.97±2.21^{c}	5.98±0.60^{d}	1.00±0.14^{a}	94.02±0.62^{b}	92.46 ± 0.02^{b}
SIDW	Gari	6.50±0.09^{f}	2.27±0.07^{b}	3.99±0.05^{b}	6.72±0.44^{e}	2.14±0.03^{b}	93.28±0.04^{b}	82.62 ± 0.02^{a}
	Fufu	2.95±0.04^{a}	1.28±0.05^{a}	4.52±0.15^{d}	4.73±0.05^{b}	2.47±0.04^{b}	95.27±0.04^{b}	90.80 ± 0.03^{b}
L30572	Gari	4.66±0.07^{c}	3.48±0.05^{c}	4.30±2.28^{d}	7.82±0.08^{e}	2.22±0.10^{b}	92.18±0.95^{b}	86.80 ± 0.30^{a}
	Lafun	2.11±0.75^{a}	2.87±0.15^{c}	3.00±0.39^{b}	2.61±0.01^{a}	2.72±0.03^{c}	97.39±0.01^{b}	83.67 ± 0.02^{a}
	Fufu	2.76±0.41^{a}	4.26±3.94^{d}	2.60±1.09^{b}	6.55±0.06^{d}	1.15±0.16^{a}	93.45±0.64^{b}	90.12 ± 0.03^{b}
SIL30572	Gari	5.79±1.65^{f}	3.20±0.20^{c}	4.49±0.14^{d}	5.82±0.04^{d}	2.09±0.03^{b}	94.18±0.04^{b}	85.96 ± 0.01^{a}
	Fufu	5.19±0.12^{d}	1.23±0.12^{a}	3.02±0.06^{c}	4.57±0.47^{b}	0.69±0.39^{a}	95.43±0.02^{b}	90.76 ± 0.03^{b}
LIL30572	Gari	5.02±0.10^{d}	2.26±0.07^{bc}	4.71±0.04^{d}	6.85±0.01^{e}	1.80±0.02^{b}	93.15±0.01^{b}	87.58 ± 0.03^{a}
	Fufu	3.80±0.04^{ab}	3.19±0.86^{c}	3.42±0.04^{c}	8.55±0.06^{f}	2.13±0.04^{b}	91.45±0.01^{b}	88.19 ± 0.01^{a}

Means with the same superscript letters within a column are not significantly different ($p < 0.05$)

KD = Kpace Dzuru, LIKD = *L. bulgaricus* fermented, SIKD = *S. cerevisea* fermented, DW = Dan Warri, LIDW = *L. bulgaricus* fermented, SIDW = *S. cerevisea* fermented, LIL30572 = Improved vaiety, LIL30572 = *L. bulgaricus* fermented, SI LIL30572= *S. cerevisea* fermented

Appendix VIII: Proximate composition of microbial fermented cassava products of TME419, KG and KB (% dry weight) of Suleja samples

Variety	product	Parameters						
		crude protein	crude fiber	crude fat	Moisture	ash	TDM	carbohydrate
TME419	Gari	8.91 ±0.12^{i}	2.86±0.07^{bc}	4.59±0.88^{e}	5.68±0.03^{d}	1.95±0.06^{b}	94.32±0.03^{b}	84.47 ± 0.02^{a}
	Fufu	3.22±0.03^{ab}	1.83±0.14^{bc}	3.25±0.13^{c}	5.67±0.14^{d}	0.78±0.03^{a}	94.33±0.04^{b}	83.09 ± 0.02^{a}
	Lafun	2.13±0.15^{a}	0.72±0.01^{a}	2.84±0.19^{b}	2.18±0.01^{a}	2.40±0.05^{b}	97.82±0.01^{b}	87.52 ± 0.02^{a}
LITME419	Gari	9.09±0.09^{i}	2.48±0.11^{c}	5.66±0.10^{f}	5.56±0.05^{d}	2.77±0.03^{c}	94..44±0.05^{b}	81.01 ± 0.01^{a}
	Fufu	4.82±0.05^{c}	0.33±0.05^{a}	3.41±0.03^{c}	5.78±0.14^{d}	0.54±0.01^{a}	94.22±0.04^{b}	92.12± 0.01^{b}
SITME419	Gari	9.95±0,07^{i}	3.44±0.11^{b}	5.32±0.12^{e}	4.95±0.21^{c}	1.38±0.01^{a}	95.05±0.04^{b}	81.60 ± 0.02^{a}
	Fufu	4.92±0.23^{c}	2.24±0.32^{a}	1.46±0.06^{a}	5.12±0.35^{c}	2.17±0.03^{b}	94.88±0.35^{b}	90.53 ±0.02^{b}
KG	Gari	7.07±0.37^{h}	3.12±0.82^{c}	2.76±2.58^{b}	6.02±0.06^{d}	2.68±0.10^{c}	93.98±0.06^{b}	85.80 ± 0.02^{a}
	Fufu	3.34±0.31^{ab}	1.25±0.20^{a}	5.36±0.08^{e}	5.84±0.06^{d}	1.49±0.04^{c}	94.16±0.07^{b}	89.71 ± 0.01^{a}
	Lafun	3.14±0.00^{ab}	1.19±0.06^{a}	5.26±0.0^{e}	3.93±0.07^{b}	1.32±0.03^{a}	96.07±0.07^{b}	89.01 ± 0.01^{a}
LIKG	Gari	8.85±0.04^{i}	3.12±0.21^{c}	3.77±0.13^{c}	5.91±1.11^{d}	2.80±0.22^{c}	94.08±1.00^{b}	83.26 ± 0.02^{a}
	Fufu	3.58±0.03^{ab}	1.05±0.44^{a}	5.81±0.04^{f}	5.73±0.10^{d}	2.50±0.04^{c}	94.27±0.06^{b}	88.2l ± 0.02^{a}
SIKG	Fufu	4.62±0.04^{bc}	1.13±0.07^{a}	5.29±0.09^{e}	4.73±0.05^{c}	1.64±0.06^{b}	95.27±0.02^{b}	88.18 ± 0.04^{a}
	Gari	10.28±0.23^{j}	3.43±0.21^{c}	3.45±0.33^{c}	6.21±0.10^{d}	1.80±0.03^{b}	93.79±0.04^{b}	82.28 ±0.03^{a}
KB	Gari	5.66± 0.09^{e}	3.28±0.10^{c}	1.48±0.05^{a}	6.39±0.02^{d}	2.68±0.10i^{c}	93.62±0.02^{b}	89.93 ± 0.03a
	Fufu	3.14±0.04^{ab}	1.12±0.30^{a}	3.06±0.08^{c}	5.76±0.04^{d}	1.32±0.03^{a}	94.24±0.05^{b}	89.22 ± 0.02^{a}
	Lafun	3.10±0.02^{b}	1.01±0.09^{a}	1.43±0.04^{a}	6.64±0.01^{f}	1.49±0.40^{a}	93.36±0.01^{b}	89.99 ± 0.04^{a}
LIKB	Gari	6.20±0.06^{f}	1.26±0.10^{a}	1.52±0.10^{a}	5.57±0.07^{d}	2.36±0.05^{a}	94.43±0.07^{b}	90.32 ±0.56^{b}
	Fufu	3.98±0.04^{b}	1.00±0.07^{a}	4.74±0.10^{e}	3.93±0.07^{a}	1.64±0.06^{a}	96.17±0.09^{b}	90.91± 0.04^{b}
SIKB	Gari	5.24±0.09^{d}	3.08±0.10^{c}	6.40±1.61^{f}	4.73±0.82^{b}	2.02±0.47^{b}	95.27±0.53^{b}	83.71 ± 0.01^{a}
	Fufu	3.78±0.08^{ab}	1.06±0.03^{a}	1.48±0.04^{a}	5.78±0.04^{d}	1.59±0.06^{b}	94.22±0.85^{b}	93.01 ±0.01^{b}

Means with the same superscript within a column are not significantly different ($p > 0.05$)

TME419 = Improved variety, LITME419 = *L. bulgaricus* fermented, KG = Karimugi, LIKG = *L. bulgaricus* fermented, SIKG = *S. cerevisea* fermented, KB = Kpace Bokun, LIKB = *L. bulgaricus* fermented, SIKB = *S. cerevisea* fermented

Appendix IX: Proximate composition of microbially fermented cassava products TMS92/0326, BI and W (% dry weight) of Suleja samples

Variety	product	Parameters						
		crude protein	crude fiber	crude fat	moisture	Ash	TDM	carbohydrate
TMS92/0326	Gari	2.74±0.08^{a}	4.18±0.18^{d}	4.78±0.12^{e}	7.55±0.02^{e}	1.63±0.03^{b}	92.45±0.02^{b}	89.38 ±0.02^{a}
	Lafun	2.40±0.04^{a}	2.13±0.12^{b}	2.21±0.12^{b}	4.57±0.02^{b}	2.16±0.02^{b}	95.43±0.02^{b}	87.19 ±0.01^{a}
	Fufu	4.91±0.09^{c}	1.70±0.50^{a}	2.52±0.05^{b}	6.18±0.17^{d}	0.62±0.04^{a}	93.82±0.06^{b}	90.0 ±0.04^{b}
LITMS92/0326	Gari	3.58±0.03^{ab}	4.04±0.23^{d}	5.13±0.08^{e}	5.56±0.05^{d}	2.38±0.03^{b}	94..44±0.05^{b}	90.71±0.01^{b}
	Fufu	5.36±0.06^{d}	1.38±0.06^{a}	3.03±1.80^{c}	6.42±0.05^{d}	1.10±0.02^{b}	93.58±0.06^{b}	90.60±0.02^{b}
SITMS92/0326	Gari	7.74±0.12^{h}	3.92±0.09^{d}	4.79±0.30^{e}	7.47±0.03^{e}	1.70±0.13^{b}	92.53±0.03^{b}	84.53 ±0.02^{a}
	Fufu	5.66± 0.09^{e}	1.60±0.01^{b}	3.87±1.80^{d}	3.93±0.07^{a}	1.69±0.03^{b}	96.07±0.09^{b}	89.95 ±0.03^{a}
BI	Gari	4.99±0.09^{c}	3.28±0.10^{c}	3.75±0.55^{d}	4.52±0.04^{b}	2.24±0.06^{b}	95.48±0.04^{b}	87.61 ±0.03^{a}
	Fufu	3.71±0.03^{ab}	2.26±0.10^{b}	3.10±0.08^{c}	5.38±0.13^{c}	1.22±0.03^{a}	94.62±0.08^{b}	89.37±0.03^{a}
	Lafun	2.64±0.05^{a}	2.16±0.02^{b}	7.26±0.06^{h}	3.12±0.09^{a}	2.38±0.03^{b}	96.88±0.02^{b}	85.46 ±0.02^{a}
LIBI	Gari	5.20±0.06d	2.92±0.10^{b}	4.52±0.10^{d}	5.57±0.07^{d}	2.36±0.05^{b}	94.43±0.07^{b}	89.62 ±0.02^{a}
	Fufu	5.58±0.03^{e}	1.89±0.44^{b}	5.81±0.04^{e}	5.99±0.10^{d}	2.50±0.04^{b}	94.01±1.52^{b}	86.80 ±0.03^{a}
SIBI	Gari	5.79±0.08^{e}	1.28±0.24^{a}	6.85±0.49^{f}	4.81±0.02^{b}	1.39±0.06^{a}	95.19±0.02^{b}	85.80 ±0.30^{a}
	Fufu	4.63±0.05^{c}	0.33±0.05^{a}	3.41±0.03^{c}	5.78±0.14^{d}	0.54±0.01^{a}	94.22±0.04^{b}	92.67±0.02^{b}
W	Lafun	3.18±0.19^{ab}	1.96±0.10^{b}	3.15±0.03^{c}	2.58±0.02^{a}	3.46±0.08^{c}	97.42±0.01^{b}	86.12 ±0.03^{a}
	Gari	3.71±0.08^{ab}	2.18±0.18^{b}	4.78±0.12^{g}	7.55±0.02^{e}	1.63±0.03^{b}	92.45±0.02^{b}	89.96±0.01^{a}
	Fufu	3.17±0.03^{ab}	0.75±0.19^{a}	4.00±0.07^{c}	6.43±0.04^{d}	1.12±0.05^{a}	95.57±0.03^{b}	91.76±0.03^{b}
SIW	Gari	5.64±0.05^{e}	2.11±0.18^{b}	5.09±0.07^{e}	5.04±0.02^{c}	1.70±0.13^{b}	94..96±0.05^{b}	87.58 ±0.03^{a}
	Fufu	3.94±0.03^{ab}	0.64±0.13^{a}	4.75±0.05^{ab}	4.81±0.02^{b}	0.04±0.06^{a}	95.19±0.02^{b}	86.19 ±0.01^{a}
LIW	Gari	6.10±0.96^{f}	2.08±0.18^{b}	7.11±0.10^{g}	6.30±0.05^{d}	1.70±0.02^{b}	93.70±0.01^{b}	83.47 ±0.02^{a}
	Fufu	3.58±0.03^{ab}	0.89±0.44^{a}	5.81±0.04^{e}	5.73±0.10^{d}	2.50±0.04^{b}	94.27±0.08^{b}	88.09 ±0.02^{a}

Means with the same superscript within a column are not significantly different ($p > 0.05$)

BI = Baba Iya, LIBI = *L. bulgaricus* fermented, SIBI = *S. cerevisea* fermented, W = Wahabi, LIW = *L. bulgaricus* fermented, SIW = *S. cerevisea* fermented, TMS92/0326 = Improved vaiety, , LITMS92/0326 = *L. bulgaricus* fermented, SITMS92/0326 = *S. cerevisea* fermented

Appendix X: Proximate composition of microbially fermented cassava products KD, DW and L30572 varieties (% dry weight) of Suleja samples.

Variety	product	Parameters						
		crude protein	crude fiber	crude fat	Moisture	ash	TDM	carbohydrate
KD	Lafun	2.60±0.15^{a}	1.49±0.14^{a}	2.62±0.29^{b}	3.52±0.21^{a}	2.64±0.02^{c}	96.48±0.21^{b}	87.52 ± 0.02^{a}
	Fufu	2.75±0.05^{a}	1.25±0.16^{a}	5.73±0.06^{f}	5.52±0.05^{d}	2.74±0.56^{c}	92.48±0.0^{3b}	89.01 ± 0.01^{a}
	Gari	4.26±0.08^{b}	2.85±0.18^{b}	2.68±0.29^{c}	6.53±0.03^{e}	2.08±0.16^{b}	93.47±0.03^{b}	90.12 ± 0.01^{b}
LIKD	Gari	4.68±0.04^{c}	2.60±0.35^{b}	2.60±0.09^{b}	8.30±0.16^{i}	1.65±0.06^{b}	91.70±1.80^{b}	90.80 ± 0.02^{b}
	Fufu	4.73±0.56^{c}	1.22±0.03^{a}	7.15±0.16^{h}	4.99±0.10^{c}	1.70±0.02^{b}	95.01±0.02^{b}	84.71 ± 0.01^{a}
SIKD	Fufu	5.74±0.12^{e}	1.14±0.09^{a}	5.79±0.30^{f}	7.47±0.03^{h}	1.70±0.13^{b}	92.53±0.03^{b}	88.01 ± 0.01^{a}
	Gari	5.66± 0.09^{e}	2.60±0.07^{b}	3.87±1.80^{d}	3.93±0.07^{a}	1.69±0.03^{b}	96.07±0.09^{b}	89.26 ± 0.02^{a}
DW	Gari	3.77±1.00^{ab}	3.65±0.86^{d}	3.35±0.55^{c}	6.04±1.06^{d}	1.35±0.59^{a}	93.96±1.47^{b}	89.2l ± 0.02^{a}
	Fufu	2.59±2.04^{a}	1.86±0.16^{b}	3.09±0.08^{c}	5.90±0.57^{d}	1.19±0.20^{a}	94.10±0.06^{b}	92.18 ± 0.04^{b}
	Lafun	2.39±0.14^{a}	1.10±0.38^{a}	2.15±0.11^{b}	3.49±0.35^{a}	1.78±0.82^{b}	96.51±0.35^{b}	88.28 ± 0.03^{a}
LIDW	Gari	5.56±0.55^{d}	2.85±0.18^{c}	5.36±3.27^{e}	4.57±1.09^{b}	1.41±0.04^{b}	95.43±1.11^{b}	86.93 ± 0.03^{a}
	Fufu	4.82±0.05^{c}	0.33±0.05^{a}	3.41±0.03^{c}	5.78±0.14^{d}	0.54±0.01^{a}	94.22±0.06^{b}	92.22 ± 0.02^{b}
SIDW	Gari	7.28±0.23^{h}	2.91±0.18^{c}	3.45±0.33^{c}	6.21±0.10^{d}	1.80±0.03^{b}	93.79±0.04b	87.99 ± 0.04^{a}
	Fufu	2.92±0.04^{a}	1.82±0.18^{b}	3.89±0.14^{d}	4.73±0.05^{b}	2.47±0.05^{b}	95.27±0.04^{b}	91.32 ± 0.56^{b}
L30572	Fufu	3.16±0.55^{ab}	0.82±0.20^{a}	1.15±0.02^{a}	6.34±0.06^{d}	1.13±0.06^{a}	93.66±0.08^{b}	94.91 ± 0.01^{b}
	Gari	4.72±1.00^{c}	2.15±0.18^{b}	3.00±0.70^{c}	5.92±0.03^{d}	1.66±0.05^{b}	94.08±0.03^{b}	89.16 ± 0.01^{a}
	Lafun	2.11±0.03^{a}	0.97±0.11^{a}	2.27±0.44^{b}	3.73±0.01^{a}	1.76±0.04^{b}	96.27±0.01^{b}	87.08 ± 0.03^{a}
SIL30572	Gari	6.33±0.96^{f}	2.00±0.22^{b}	3.29±0.14^{c}	5.82±0.05^{d}	1.87±0.03^{b}	94.18±0.05^{b}	87.38 ± 0.03^{a}
	Fufu	5.19±0.13^{d}	0.67±0.07^{a}	3.02±0.06^{c}	5.19±0.02^{c}	0.50±0.36^{a}	94.81±0.05^{b}	91.89 ± 0.04^{b}
LIL30572	Fufu	4.82±0.05^{c}	0.33±0.05^{a}	3.41±0.03^{c}	5.58±0.14^{d}	0.54±0.01^{a}	94.22±0.01^{b}	92.89 ± 0.03^{b}
	Gari	7.28±0.23^{h}	2.11±0.22^{b}	3.45±0.33^{c}	6.21±0.10^{d}	1.80±0.03^{b}	93.79±0.04b	87.81 ± 0.01^{a}

Means with the same superscript within a column are not significantly different ($p > 0.05$)

KD = Kpace Dzuru, LIKD = *L. bulgaricus* fermented, SIKD = *S. cerevisea* fermented, DW = Dan Warri, LIDW= *L. bulgaricus* fermented, SIDW = *S. cerevisea* fermented, L30572= Improved vaiety, ,*LIL30572 = L. bulgaricu*s fermented, SIL30572= *S. cerevisea* fermented

Result of ant-nutrient contents of cassava products (inoculated and non inoculated)

Appendix XI Selected anti-nutrient compositions of microbial fermented cassava products of TME419, KG and TMS92/0326 varieties of Suleja samples

Variety	Product	Parameters				
		Cyanide µg/100g	Oxalate mg/100g	phytate (mg/100g)	tannins g/100g	saponnins (%)
TME419	Gari	2.45±0.05^{b}	9.00±0.15^{d}	339.50±8.00^{c}	6.79±1.40^{c}	1.59±0.00^{a}
	Fufu	1.03±0.10^{a}	8.93±0.25^{c}	302.41±7.49^{c}	5.68±0.61^{b}	4.82±0.00^{c}
	Lafun	1.35±0.08^{a}	9.14±0.00^{d}	367.00±4.70^{c}	7.42±0.72^{d}	3.43±0.00c
LITME419	Gari	1.50±0.42^{a}	8.09±0.25^{c}	291.22±3.60^{b}	5.18±0.58^{b}	1.02±0.00^{a}
	Fufu	0.94±0.21^{a}	7.11±0.03^{b}	242.00±6.70^{b}	5.32±1.07^{b}	3.48±0.00c
SITME419	Gari	1.95±0.05^{a}	8.84±0.15^{c}	277.50±8.87^{b}	5.73±0.57^{b}	1.44±0.00^{a}
	Fufu	0.82±0.12^{a}	6.26±0.02^{a}	248.04±6.90^{b}	4.89±0.62^{a}	3.22±0.01^{c}
KG	Gari	1.51±0.03^{a}	7.98±0.50^{b}	300.50±0.45^{c}	8.22±1.81^{e}	1.94±0.01^{b}
	Fufu	2.89±0.10^{c}	8.23±0.10^{c}	186.54±3.94^{a}	7.66±0.94^{d}	2.17±0.00^{b}
	Lafun	3.15±0.05^{c}	9.22±0.21^{d}	299.00±4.70^{b}	8.39±0.40^{e}	3.99±0.01^{c}
LIKG	Gari	1.21±0.03^{a}	7.12±0.25^{b}	246.64±7.80^{b}	7.37±0.69^{d}	1.31±0.00^{a}
	Fufu	0.85±0.09^{a}	8.11±0.I5^{c}	171.50±8.85^{a}	6.95±2.01^{c}	2.02±0.00^{b}
SIKG	Fufu	1.01±0.07^{a}	8.14±0.00^{c}	164.54±3.84^{a}	5.79±0.70^{b}	1.98±0.00^{b}
	gari	1.02±0.52^{a}	7.29±0.41^{b}	278.50±0.47^{b}	6.54±1.21^{c}	1.89±0.00^{b}
TMS92/0326	Gari	1.33±0.03^{a}	6.20±0.05^{a}	168.38±7.50^{a}	5.90±2.13^{b}	3.54±0.01^{c}
	Lafun	2..83±0.21^{c}	7.56±0.08^{b}	228.50±4.62^{b}	8.43±1.70^{e}	4.85±0.00^{d}
	Fufu	2.34±0.05^{b}	6.23±0.25^{a}	201.54±8.13^{b}	6.20±0.54^{c}	3.30±0.01^{c}
SITMS92/0326	Gari	0.92±0.10^{a}	5.86±0.00^{a}	145.69±5.45^{a}	5.35±1.87^{b}	1.89±0.00^{a}
	Fufu	0.78±0.02^{a}	6.01±0.20^{a}	158.19±5.23^{a}	5.23±0.68^{b}	3.21±0.02^{c}
LITMS92/0326	Gari	1.38±0.06^{a}	5.83±0.10^{a}	146.50±0.45^{a}	5.45±1.41^{b}	2.13±0.00^{b}
	Fufu	0.85±0.00^{a}	6.00±0.25^{a}	176.50±0.45^{a}	4.05±0.32^{a}	2.74±0.00^{c}

Means with the same superscript within a column are not significantly different ($p > 0.05$)

TME419 = Improved variety, LITME419 = *L. bulgaricus* fermented, KG = Karimugi, LIKG = *L. bulgaricus* fermented, SIKG = *S. cerevisea* fermented, TMS92/0326 = Improved variety, SITMS = *S. cerevisea* fermented, LITMS = *L. bulgaricus* fermented

Appendix XII: Selected Anti-nutrient compositions of microbial fermented cassava products of KB, BI and W varieties of Suleja samples

Variety	product	Parameters				
		cyanide µg/100g	oxalate mg/100g	phytate (mg/100g)	tannins g/100g	saponnins (%)
KB	Gari	2.77±0.15^{c}	9.44±1.21^{e}	297.50±0.45^{b}	7.53±2.40^{f}	5.06±0.00^{e}
	Lafun	3.48±0.03^{c}	9.71±0.25^{e}	267.50±8.05^{b}	8.62±1.00^{g}	4.49±0.01^{d}
	Fufu	1.05±0.08^{a}	8.29±0.50^{d}	252.41±7.41^{b}	6.91±0.09^{e}	2.25±0.10^{b}
LIKB	Gari	1.7±0.05a^{b}	9.03±1.23^{e}	201.00±4.70^{b}	6.42±1.14^{e}	4.21±0.02^{d}
	Fufu	0.98±0.13^{a}	8.20±0.28^{d}	214.22±3.32^{b}	5.89±2.11^{d}	1.89±0.00^{a}
SIKB	Gari	2.70±0.23^{b}	9.23±0.25^{e}	242.00±6.70^{b}	4.98±106^{c}	3.91±0.02^{d}
	Fufu	0.72±0.21^{a}	8.23±0.11^{d}	237..50.±8.8^{b}	5.23±0.82^{d}	2.21±0.12^{b}
BI	Gari	5.92±0.00^{e}	10.11±0.00^{f}	248.04±6.90^{b}	6.19±0.03^{e}	3.89±0.00^{c}
	Fufu	4.20±0.08^{d}	11.27±1.01^{g}	204.50±0.45^{b}	5.86±0.55^{d}	2.19±0.00^{b}
	Lafun	6.25±0.08^{f}	12.93±0.08^{h}	267.54±3.94^{b}	6.00±0.92^{e}	4.27±0.00^{d}
LIBI	Gari	2.22±0.04^{b}	6.23±0.25^{b}	177.00±4.70^{a}	4.13±1.34^{c}	2.45±0.00^{b}
	Fufu	1.84±0.21^{b}	6.01±0.15^{b}	196.50±7.80^{a}	4.81±2.40^{c}	3.48±0.00^{c}
SIBI	Gari	1.75±0.05^{b}	5.83±0.02^{a}	201.50.±8.8^{b}	5.00±0.84^{d}	4.44±0.00^{d}
	Fufu	1.10±0.21^{a}	5.11±1.00^{a}	164.54±3.84^{a}	5.11±0.61^{d}	4.22±0.01^{d}
W	Fufu	0.89±0.15^{a}	6.23±0.45^{b}	312.09±6.41^{c}	2.99±0.07^{a}	3.54±0.01^{c}
	Gari	2.31±2.99^{b}	9.01±0.07^{d}	310.50±8.30^{c}	3.89±1.00^{b}	2.05±0.00^{b}
	Lafun	6.34±0.05^{f}	12.93±0.08^{h}	278.50±4.45^{b}	4.89±0.58^{c}	5.69±0.01^{e}
SIW	Fufu	0.82±0.10^{a}	5.74±0.20^{a}	271.27±5.37^{b}	2.97±1.26^{a}	2.57±0.00^{b}
	Gari	0.78±0.02^{a}	8.48±1.11^{c}	291.90±8.00^{b}	2.71±0.02^{a}	2.21±0.02^{b}
LIW	Gari	1.92±0.04^{b}	8.70±0.25^{c}	304.58±3.90^{c}	2.03±1.04^{a}	2.00±0.00^{b}
	Fufu	0.86±0.21^{a}	6.14±0.00^{b}	244.10±6.44^{b}	2.44±0.00^{a}	2.48±0.00^{b}

Means with the same superscript within a column are not significantly different ($p > 0.05$)

BI = Baba Iya, LIBI = *L. bulgaricus* fermented, SIBI = *S. cerevisea* fermented, KB = Kpace Bokun, LIKB = *L. bulgaricus* fermented, SIKB = *S. cerevisea* fermented, TMS92/0326 = Improved variety, W = Wahabi, SIW = *S. cerevisea* fermented, LIW = *L. bulgaricus* fermented

Appendix XIII: Selected anti-nutrient compositions of microbial fermented cassava products of KD, DW and L30572 varieties of Suleja samples

Variety	Product	Parameters				
		Cyanide µg/100g	Oxalate mg/100g	phytate (mg/100g)	tannins g/100g	saponins (%)
KD	Gari	1.72±0.03^{b}	9.23±0.08^{e}	271.07±5.26^{b}	7.84±0.74^{e}	4.44±0.00^{d}
	Fufu	1.05±0.05^{a}	7.21±1.05^{c}	208.90±7.45^{b}	6.88±0.34^{d}	4.22±0.01^{d}
	Lafun	2.45±0.10^{b}	9.86±0.22^{e}	319.50±8.0^{c}	7.56±0.07^{e}	3.54±0.01^{c}
LIKD	Gari	1.45±0.05^{a}	9.04±0.16^{e}	202.41±7.42^{b}	6.23±1.53^{d}	2.05±0.00^{c}
	Fufu	1.08±0.10^{a}	6.99±0.00^{b}	197.00±4.70^{b}	5.44±1.31^{c}	3.69±0.01^{c}
SIKD	Gari	1.56±0.05^{a}	8.89±1.28^{d}	211.22±3.4^{b}	6.39±1.40^{d}	2.57±0.00^{b}
	Fufu	1.03±0.10^{a}	6.80±0.25^{b}	201.00±6.70^{b}	5.88±0.61^{c}	3.21±0.02^{c}
DW	Gari	1.69±0.39^{b}	9.23±0.81^{e}	287.50.±8.8^{b}	7.42±0.72^{e}	4.07±0.00^{d}
	Fufu	0.99±0.06^{a}	5.28±1.81^{a}	298.04±6.90^{b}	7.18±0.58^{c}	3.02±0.01^{c}
	Lafun	4.22±1.44^{d}	9.57±0.25^{e}	248.50±0.45^{b}	5.32±1.07^{c}	3.24±0.01^{c}
LIDW	Gari	1.51±0.26^{a}	9.03±0.04^{e}	177.54±3.94^{a}	6.03±0.57^{d}	2.35±0.00^{b}
	Fufu	0.87±0.06^{a}	5.18±0.29^{a}	217.00±4.70^{b}	3.89±0.62^{a}	3.01±0.01^{c}
SIDW	Gari	1.51±0.05^{a}	9.40±0.01^{e}	226.70±7.80^{b}	4.22±1.81^{b}	2.11±0.00^{b}
	Fufu	1.18±0.10^{a}	5.21±0.65^{a}	201.50±8.81^{b}	5.86±0.94^{e}	2.98±0.02a
L30572	Gari	2.86±0.30^{c}	9.10±1.08^{e}	164.54±3.84^{a}	7.39±0.40^{e}	2.13±0.00^{b}
	Fufu	1.42±0.11^{a}	6.41±0.10^{b}	161.30±7.45^{a}	7.67±0.69^{e}	3.62±0.00^{d}
	Lafun	3.82±1.84^{d}	8.22±0.14^{d}	173.43±3.40^{a}	6.95±2.01^{d}	6.09±0.00^{f}
SIL30572	Gari	1.13±0.03^{a}	7.13±1.08^{c}	158.50±3.49^{a}	6.09±0.20^{d}	2.30±0.01^{b}
	Fufu	0.73±0.13^{a}	6.48±0.25^{b}	140.41±6.25^{a}	6.93±1.70^{d}	3.27±0.00^{c}
LIL30572	Gari	1.31±0.26^{a}	7.14±0.00^{c}	155.10±9.25^{a}	6.50±2.13^{d}	2.00±0.01^{b}
	Fufu	0.68±0.06^{a}	8.14±0.00^{d}	138.50±0.45^{a}	5.09±1.70^{c}	2.87±0.00^{b}

Means with the same superscript within the same column are not significantly different ($p > 0.05$) KD = Kpace Dzuru, LIKD = *L. bulgaricus* fermented, SIKD = *S. cerevisea* fermented, DW = Dan Warri, LIDW = *L. bulgaricus* fermented, SIDW = *S. cerevisea* fermented, L30572 = Improved variety, SI L30572 = *S. cerevisea* fermented, LI L30572 = *L. bulgaricus* fermented

Appendix XIV: Selected anti-nutrient compositions of microbial fermented cassava products of KB, BI and W varieties of Kontagora samples

Variety	product	Parameters				
		Cyanide (µg/100g)	Oxalate mg/100g	Tannins g/100g	Phytate (mg/100g)	Saponins (%)
KB	Gari	4.14±0.15^{d}	7.56±0.08^{c}	6.19±0.03^{e}	310.50±0.85	4.46±0.00^{d}
	Lafun	3.18±0.03^{c}	8.23±0.25^{d}	7.11±0.55^{f}	329.50±8.10^{c}	4.30±0.01^{d}
	Fufu	0.95±0.08^{a}	6.29±0.50^{b}	6.00±0.92^{e}	311.01±6.23^{c}	3.00±0.10a^{c}
LIKB	Gari	1.84±0.05^{b}	7.03±1.23^{c}	4.13±1.34^{c}	298.00±4.70^{b}	2.62±0.02^{b}
	Fufu	1.05±0.13^{a}	6.00±0.50^{b}	5.71±2.40^{d}	267.22±3.20^{b}	2.29±0.00^{b}
SIKB	Gari	3.42±0.23^{c}	5.23±0.25^{a}	5.22±0.84^{d}	202.00±5.70^{b}	3.91±0.03^{c}
	Fufu	5.72±0.21^{e}	5.20±0.11^{a}	5.86±0.61^{d}	247.50±8.08^{b}	2.21±0.12^{b}
BI	Gari	6.22±0.00^{f}	11.23±1.31^{g}	2.97±0.07^{a}	239.04±6.22^{b}	4.49±0.00^{d}
	Fufu	4.28±0.08^{d}	10.01±0.15^{f}	3.89±1.00^{b}	208.50±0.45^{b}	2.19±0.00^{b}
	Lafun	6.45±0.08^{f}	11.93±0.08^{g}	4.89±0.58^{c}	197.54±3.94^{a}	4.18±0.00^{d}
LIBI	Gari	2.92±0.04^{c}	8.24±0.25^{d}	2.99±1.26^{a}	209.00±4.70^{b}	2.45±0.00^{b}
	Fufu	2.04±0.21^{b}	9.01±0.15^{e}	2.71±0.02^{a}	256.80±4.80^{b}	3.48±0.00^{c}
SIBI	Gari	1.95±0.05^{b}	9.86±0.20^{e}	2.03±1.04^{a}	201.50±8.38^{b}	3.42±0.00^{c}
	Fufu	1.14±0.21^{a}	9.11±1.00e	3.44±0.00^{b}	164.54±3.84^{a}	0.04±0.01^{a}
W	Fufu	0.99±0.15^{a}	8.86±0.22^{d}	8.64±0.74^{g}	300.09±6.41^{c}	3.44±0.01^{c}
	Gari	2.31±2.99^{b}	9.51±0.07^{e}	7.18±0.34^{f}	322.50±8.30^{c}	2.05±0.00^{b}
	Lafun	4.34±0.05^{d}	12.93±0.08^{h}	7.56±0.07^{f}	308.50±4.45^{c}	3.82±0.01^{c}
SIW	Fufu	0.92±0.10^{a}	8.04±0.02^{d}	6.23±1.53^{e}	271.27±5.37^{b}	2.57±0.00^{b}
	Gari	1.78±0.02^{b}	8.91±0.08^{d}	6.44±1.31^{e}	291.90±8.00^{b}	1.98±0.01^{a}
LIW	Gari	1.34±0.05^{a}	9.00±0.25^{e}	6.43±1.21^{e}	310.58±3.90^{c}	2.00±0.00^{b}
	Fufu	1.00±0.13^{a}	6.14±0.00^{b}	6.00±1.53^{e}	244.10±6.44^{b}	3.10±0.01^{c}

Means with the same superscript within a column are not significantly different ($p > 0.05$)

BI = Baba Iya, LIBI = *L. bulgaricus* fermented, SIBI = *S. cerevisea* fermented, KB=KpaceBokun, LIKB= *L. bulgaricus* fermented, SIBK = *S. cerevisea* fermented, W = Wahabi, , LIW = *L. bulgaricus* fermented, SIW = *S. cerevisea* fermented

Appendix XV: Selected anti-nutrient compositions of microbial fermented cassava products of KD, DW and L30572 varieties of Kontagora samples

Variety	product	Parameters				
		Cyanide	oxalate mg/100g	tannins g/100g-1	phytate (mg100g-1)	saponnins
KD	Gari	2.72±0.03^{c}	9.23±0.08^{e}	6.19±0.03^{e}	272.07±6.00^{b}	4.27±0.00^{d}
	Lafun	2.85±0.00^{c}	9.70±1.05^{e}	7.11±0.55^{f}	204.90±7.35^{b}	2.50±0.05^{g}
	Fufu	1.05±0.13^{a}	7.21±0.22^{c}	6.00±0.92^{e}	300.50±8.00^{c}	2.34±0.56^{b}
LIKD	Gari	2.21±0.29^{b}	9.04±0.16^{e}	4.13±1.34^{c}	210.41±7.54^{b}	1.41±0.08^{a}
	Fufu	0.98±0.05^{a}	6.99±0.00^{b}	5.71±2.40^{d}	197.00±4.70^{a}	2.11±0.56^{b}
SIKD	Gari	2.01±0.02^{b}	8.89±1.28^{d}	5.22±0.84^{d}	200.22±3.46^{b}	1.09±0.08^{a}
	Fufu	0.86±0.05^{a}	6.33±0.15^{b}	5.86±0.61^{d}	178.00±6.70^{a}	4.70±0.03^{d}
DW	Gari	2.19±0.39^{b}	8.64±0.81^{d}	2.97±0.07^{a}	287.50±8.87^{b}	1.72±0.00^{a}
	Fufu	1.27±0.06^{a}	5.28±1.81^{a}	3.89±1.00^{b}	266.04±6.90^{b}	2.53±0.01^{b}
	Lafun	5.02±2.68^{e}	9.13±0.25^{e}	4.89±0.58^{c}	228.50±0.45^{b}	4.43±0.04^{d}
LIDW	Gari	1.68±0.26^{b}	8.03±0.04^{d}	2.59±1.26^{a}	197.54±3.94^{a}	1.26±0.00^{a}
	Fufu	0.87±0.06^{a}	5.18±0.29^{a}	2.71±0.02^{a}	207.00±4.70^{b}	2.18±0.01^{b}
SIDW	Gari	1.44±0.07^{a}	8.47±0.01^{d}	2.03±1.04^{a}	276.70±7.80^{b}	2.05±0.06^{b}
	Fufu	0.99±0.06^{a}	5.00±0.65^{a}	3.44±0.00^{b}	201.50±8.28^{b}	4.76±0.09^{d}
L30572	Gari	1.38±0.06^{a}	7.99±0.10^{c}	8.64±0.74^{g}	186.54±3.84^{a}	1.77±0.00^{a}
	Fufu	1.80±0.00^{b}	5.83±1.01^{a}	7.18±0.34^{f}	148.30±7.45^{a}	5.62±0.00^{a}
	Lafun	3.82±1.84^{d}	8.02±0.11^{d}	7.56±0.07^{f}	199.43±3.20^{a}	5.94±0.00^{a}
SIL30572	Gari	1.33±0.03^{a}	7.054±1.08^{c}	6.23±1.08^{e}	121.50±3.49^{a}	1.54±0.01^{a}
	Fufu	1.05±0.13^{a}	5.18±0.21^{a}	6.24±1.31^{e}	132.41±6.25^{a}	3.27±0.00^{c}
LIL30572	Gari	1.68±0.26^{b}	7.14±1.00^{c}	7.83±1.53^{f}	119.10±8.25^{a}	1.07±0.01^{a}
	Fufu	0.87±0.06^{a}	5.14±1.12^{a}	6.04±1.26^{e}	101.50±0.45^{a}	2.98±0.00^{b}

Means with the same superscript within a column are not significantly different ($p > 0.05$)

KD = Kpace Dzuru, LIKD = *L. bulgaricus* fermented, SIKD = *S. cerevisea* fermented, DW = Dan Warri, LIDW = *L. bulgaricus* fermented, SIDW = *S. cerevisea* fermented, L30572 = Improved variety, SI L30572= *S. cerevisea* fermented, LI L30572 = *L. bulgaricus* fermented

Appendix XVI: Selected anti-nutrient compositions of microbial fermented cassava products TME419, KG and TMS92/0326 varieties of Kontagora samples

Variety	product	parameters				
		Cyanide µg/100g	oxalate mg/100g	tannins g/100g	phytate (mg/100g)	saponnins
TME419	Gari	1.68±0.05^{b}	9.18±0.03^{e}	6.50±2.13^{e}	328.50±8.02^{c}	1.72±0.00^{a}
	Fufu	1.47±0.10^{a}	9.11±0.03^{e}	5.93±1.70^{d}	309.41±7.43^{c}	4.77±0.00c
	Lafun	2.30±0.08^{b}	9.14±0.00^{e}	7.20±0.54^{f}	401.00±4.70^{d}	3.99±0.00^{b}
LITME419	Gari	1.62±0.42^{b}	8.29±0.25^{d}	5.35±1.87^{d}	284.22±3.40^{b}	1.02±0.00^{a}
	Fufu	0.94±0.21^{a}	9.04±0.03^{e}	4.23±0.68^{c}	242.00±6.70^{b}	4.02±0.00^{b}
SITME419	Gari	1.49±0.05^{a}	8.84±0.15^{d}	6.00±1.41^{e}	277.50±8.81^{b}	1.58±0.00^{a}
	Fufu	1.03±0.10^{a}	8.83±0.02^{d}	3.75±0.32^{b}	248.04±6.90^{b}	3.22±0.01^{ab}
KG	Gari	2.91±0.10^{b}	8.18±0.21^{d}	9.53±2.40^{h}	299.00±0.45^{b}	2.02±0.01^{a}
	Fufu	2.89±0.10^{c}	8.23±0.10^{d}	6.62±1.00^{e}	193.54±3.74^{a}	2.17±0.00^{a}
	Lafun	3.50±0.05^{d}	9.22±0.21^{e}	9.71±0.09^{h}	344.00±4.70^{c}	4.18±0.01^{b}
LIKG	Gari	1.21±0.03^{a}	7.52±0.25^{c}	6.42±1.14^{e}	296.64±7.80^{b}	1.31±0.00^{a}
	Fufu	0.80±0.09^{a}	7.73±0.10^{c}	5.89±2.11^{d}	190.50±6.23^{a}	2.12±0.00^{a}
SIKG	Fufu	1.01±0.07^{a}	8.00±1.00^{d}	4.98±106^{c}	164.54±3.84^{a}	1.98±0.00^{a}
	gari	1.02±0.52^{a}	7.29±0.41^{c}	7.23±0.82^{f}	278.50±0.47^{b}	1.89±0.00^{a}
TMS92/0326	Gari	1.43±0.03^{a}	8.06±1.22^{d}	5.22±0.55^{d}	181.12±7.60^{a}	3.54±0.01^{ab}
	Lafun	3.15.±0.21^{c}	7.56±0.08^{c}	4.75±0.74^{c}	277.50±4.62^{b}	3.95±0.00^{b}
	Fufu	4.34±0.05^{d}	6.23±0.25^{b}	4.19±1.21^{c}	220.54±8.13^{b}	3.27±0.01^{ab}
SITMS92/0326	Gari	0.99±0.10^{a}	7.00±1.22^{c}	4.34±2.40^{c}	145.69±5.45^{a}	2.15±0.00^{a}
	Fufu	1.72±0.02^{b}	6.01±0.08^{b}	3.53±1.10^{b}	158.19±5.23^{a}	3.08±0.02ab
LITMS92/0326	Gari	1.56±0.06^{a}	7.23±0.25^{c}	4.16±2.11^{c}	146.50±0.45^{a}	2.13±0.00^{a}
	Fufu	1.85±0.00^{b}	5.76±1.22^{a}	3.53±0.56^{b}	208.50±0.45^{b}	2.48±0.00^{ab}

Means with the same superscript within a column are not significantly different ($p > 0.05$)

TME419 = Improved vaiety, SITME419 = *S. cerevisea* fermented, LITME419 = *L. bulgaricus* fermented, KG = Karimugi, LIKG = *L. bulgaricus* fermented, SIKG = *S. cerevisea* fermented TMS92/0326= Improved vaiety, LITMS92/0326 = *L. bulgaricus* fermented, SITMS92/0326 =

S. cerevisea fermented

Appendix XVII: Selected anti-nutrient compositions of microbial fermented cassava products of TME419, KG and TMS92/0326 varieties of Bida samples

Variety	product	Parameters				
		Cyanide		phytate ($mg100g^{-1}$)	Tannins g/100g	saponnins
TME419	Gari	2.31±2.99b	$10.12±0.06^{f}$	$319.50±8.04^{c}$	$5.12±1.18^{d}$	$1.02±0.00^{a}$
	Fufu	1.25±0.10a	$8.15±0.03^{d}$	$292.41±7.41^{b}$	$4.01±0.40^{c}$	4.64±0.00c
	Lafun	$2.80±0.08^{c}$	$9.14±0.00^{e}$	$306.00±4.70^{d}$	$6.85±1.04^{e}$	$3.38±0.00^{b}$
LITME419	Gari	$1.44±0.42^{a}$	$9.26±1.25^{e}$	$271.22±3.43^{b}$	$4.64±1.07^{c}$	$1.02±0.00^{a}$
	Fufu	$1.22±0.21^{a}$	$7.00±0.06^{c}$	$241.00±6.60^{b}$	$3.42±1.73^{b}$	$4.02±0.00^{b}$
SITME419	Gari	$0.73±0.05^{a}$	$8.84±0.15^{d}$	$279.50±8.81^{b}$	$5.33±0.45^{d}$	$1.75±0.00^{a}$
	Fufu	$0.97±0.10^{a}$	$7.34±0.02^{c}$	$248.04±6.90^{b}$	$5.00±1.73^{d}$	$3.29±0.01^{ab}$
KG	Gari	$2.97±0.03^{c}$	$9.10±1.01^{e}$	$302.30±0.45^{c}$	$6.50±2.13^{e}$	$1.93±0.01^{a}$
	Fufu	$2.89±0.10^{c}$	$6.93±1.17^{b}$	$197.54±3.94^{c}$	$6.93±1.70^{e}$	$3.07±0.00^{b}$
	Lafun	$3.50±0.05^{c}$	$9.22±0.21^{e}$	$359.30±4.70^{c}$	$9.20±0.54^{h}$	$4.12±0.01^{c}$
LIKG	Gari	$1.21±0.03^{a}$	$7.52±0.25^{c}$	$296.64±7.80^{b}$	$5.35±1.87^{d}$	$3.30±0.00^{b}$
	Fufu	$0.80±0.09^{a}$	$6.22±0.10^{b}$	$182.50±8.89^{a}$	$5.23±0.68^{d}$	$4;00±0.00^{a}$
SIKG	Fufu	$1.01±0.07^{a}$	$6.08±1.00^{b}$	$164.54±3.84^{a}$	$6.45±1.41^{e}$	$1.71.±0.00^{a}$
	gari	$1.02±0.52^{a}$	$7.29±0.41^{c}$	$278.50±0.47^{b}$	$6.05±0.32^{e}$	$1.o9±0.00^{a}$
TMS92/0326	Gari	$2.30±0.03^{b}$	$8.12±1.32^{d}$	$184.38±7.50^{a}$	$9.53±2.40^{h}$	$3.54±0.01^{ab}$
	Fufu	$6.15.±0.21^{f}$	$7.06±0.08^{c}$	$278.50±4.62^{b}$	$6.62±1.00^{e}$	$4.36±0.00^{c}$
	Lafun	$2.30±0.05^{b}$	$5.83±0.15^{a}$	$220.54±8.13^{b}$	$8.71±0.09^{g}$	$3.30±0.01^{ab}$
SITMS92/0326	Gari	$1.05±0.10^{a}$	$7.49±1.62^{c}$	$145.69±5.45^{a}$	$6.42±1.14^{e}$	$2.07±0.00^{a}$
	Fufu	$1.72±0.02^{b}$	5.38±1.08c	$158.19±5.23^{a}$	$5.89±2.11^{d}$	$2.90±0.02^{ab}$
LITMS92/0326	Gari	$1.56±0.06^{a}$	$7.23±0.25^{c}$	$146.50±0.45^{a}$	$4.98±1.06^{c}$	$2.13±0.00^{a}$
	Fufu	$0.85±0.78^{a}$	$5.18±1.09^{e}$	$208.50±0.45^{b}$	$4.23±0.82^{c}$	$2.74±0.00^{ab}$

Means with the same superscript within a column are not significantly different ($p > 0.05$)

TME419 = Improved variety, SITME419 = *S. cerevisea* fermented, LITME419 = *L. bulgaricus* fermented, KG = Karimugi, LIKG = *L. bulgaricus* fermented, SIKG = *S. cerevisea* fermented, TMS92/0326= Improved vaiety, , LITMS92/0326 = *L. bulgaricus* fermented, SITMS92/0326 = *S. cerevisea* fermented

Appendix XVIII: Selected anti-nutrient compositions of microbial fermented cassava products of KB, BI and W varieties of Bida samples

Variety	Product	Parameters				
		Cyanide µg/100g	Oxalate mg/100g	phytate ($mg100g^{-1}$)	tannins g/100g	saponnins (%)
KB	Gari	3.77 ± 0.15^{d}	8.50 ± 0.18^{d}	308.50 ± 0.45^{c}	4.82 ± 0.55^{c}	5.06 ± 0.00^{d}
	Lafun	3.25 ± 0.20^{c}	8.21 ± 0.25^{d}	339.50 ± 8.03^{c}	7.50 ± 2.13^{f}	4.36 ± 0.01^{c}
	Fufu	$1.01.\pm0.19^{a}$	6.29 ± 0.50^{b}	302.41 ± 7.42^{c}	6.93 ± 1.70^{e}	2.65 ± 0.10^{ab}
LIKB	Gari	1.70 ± 0.05^{b}	7.83 ± 1.26^{c}	201.00 ± 4.70^{b}	4.20 ± 0.54^{c}	1.69 ± 0.02^{a}
	Fufu	0.84 ± 0.13^{a}	6.08 ± 1.10^{b}	291.22 ± 3.47^{b}	5.35 ± 1.87^{d}	1.61 ± 0.00^{a}
SIKB	Gari	2.85 ± 0.23^{c}	6.93 ± 0.25^{b}	242.00 ± 6.70^{b}	5.23 ± 0.68^{d}	2.41 ± 0.03^{b}
	Fufu	0.69 ± 0.21^{a}	6.23 ± 0.16^{b}	277.50 ± 8.82^{b}	6.45 ± 1.41^{e}	2.21 ± 0.12^{b}
BI	Gari	4.70 ± 0.00^{e}	10.28 ± 1.01^{f}	248.04 ± 6.90^{b}	6.19 ± 0.03^{e}	4.49 ± 0.00^{c}
	Fufu	4.37 ± 0.08^{d}	9.09 ± 0.18^{e}	208.50 ± 0.45^{b}	7.11 ± 0.55^{f}	4.95 ± 0.00^{d}
	Lafun	6.27 ± 0.08^{f}	9.87 ± 0.09^{e}	257.54 ± 3.94^{b}	6.00 ± 0.92^{e}	4.18 ± 0.00^{c}
LIBI	Gari	2.95 ± 0.05^{a}	8.84 ± 0.25^{d}	199.00 ± 4.70^{a}	4.13 ± 1.34^{c}	2.44 ± 0.00^{a}
	Fufu	3.09 ± 0.03^{a}	8.40 ± 2.10^{d}	196.50 ± 7.80^{a}	5.71 ± 2.40^{d}	2.00 ± 0.00^{a}
SIBI	Gari	1.62 ± 0.04^{b}	9.86 ± 0.20^{e}	201.50 ± 8.81^{b}	5.22 ± 0.84^{d}	4.44 ± 0.00^{c}
	Fufu	2.18 ± 0.03^{a}	8.99 ± 1.06^{d}	164.54 ± 3.84^{a}	5.86 ± 0.61^{d}	1.96 ± 0.00^{a}
W	Gari	1.42 ± 0.03^{a}	8.14 ± 0.07^{d}	300.09 ± 6.41^{c}	2.97 ± 0.07^{a}	2.45 ± 0.00^{a}
	Lafun	3.80 ± 0.05^{d}	9.01 ± 0.22^{e}	320.50 ± 8.30^{c}	3.89 ± 1.00^{b}	3.87 ± 0.00^{c}
	Fufu	1.55 ± 0.04^{a}	6.93 ± 0.08^{c}	308.50 ± 4.45^{c}	4.89 ± 0.58^{c}	4.82 ± 0.00^{d}
LIW	Fufu	1.03 ± 0.05^{a}	5.04 ± 0.02^{a}	271.27 ± 5.37^{b}	2.99 ± 1.26^{a}	2.89 ± 0.00^{a}
	Gari	1.40 ± 0.05^{a}	8.00 ± 0.18^{d}	291.90 ± 8.00^{b}	2.71 ± 0.02^{a}	1.43 ± 0.00^{ab}
SIW	Gari	1.02 ± 0.03^{a}	7.00 ± 0.25^{c}	304.58 ± 3.90^{c}	2.03 ± 1.04^{a}	2.38 ± 0.01^{ab}
	Fufu	0.92 ± 0.10^{a}	6.14 ± 0.00^{b}	244.10 ± 6.44^{b}	3.44 ± 0.00^{b}	$4.36.\pm0.00^{d}$

Means with the same superscript within a column are not significantly different ($p > 0.05$)

W = Wahabi SIW = *S. cerevisea* fermented, LIW = *L. bulgaricus* fermented, BI = Baba Iya, LIBI = *L. bulgaricus* fermented, SIBI = *S. cerevisea* fermented, KB=Kpace Bokun, LIKB= *L. bulgaricus* fermented, SIBK = *S. cerevisea* fermented

Appendix XIX: Selected anti-nutrient compositions of microbial fermented cassava products of KD, DW and L30572 varieties of Bida samples

Variety	product	Parameters				
		cyanide µg/100g	oxalate mg/100g	phytate (mg/100g)	tannins mg/100g	saponnins (%)
KD	Gari	2.23±0.05^{b}	9.23±0.08^{e}	321.07±5.26^{c}	8.64±0.74^{f}	3.79±0.00^{c}
	Fufu	1.10±0.22^{a}	9.71±1.05^{e}	228.90±7.45^{b}	7.18±0.34^{f}	2.32±0.00^{b}
	Lafun	2.85±0.10^{c}	7.21±0.22^{c}	339.50±8.01^{c}	7.56±0.07^{f}	8.16±0.00^{g}
LIKD	Gari	1.92±0.47^{b}	9.04±0.16^{e}	272.41±7.44^{b}	6.23±1.53^{e}	1.71±0.00a
	Fufu	1.06±0.05^{a}	6.99±0.00^{b}	197.00±4.70^{a}	6.44±1.31^{e}	2.30.±0.00^{d}
SIKD	Gari	1.33±0.30^{a}	8.89±1.28^{c}	291.22±3.43^{b}	5.22±0.84^{d}	3.12±0.00^{c}
	Fufu	1.00±0.05^{a}	7.33±0.15^{c}	201.00±6.70^{b}	5.86±0.61^{d}	2.09±0.00^{d}
DW	Gari	1.53±0.03^{a}	8.44±0.81^{d}	287..50.±8.8^{b}	2.97±0.07^{a}	1.87±0.04^{a}
	Lafun	5.02±2.68^{e}	5.28±1.81^{a}	298.04±6.90^{b}	3.89±1.00^{b}	4.86±0.02^{d}
	Fufu	1.01±0.19^{a}	7.13±0.25^{c}	248.50±0.45^{b}	4.29±0.58^{c}	4.58±0.21^{d}
LIDW	Gari	1.22±0.03^{a}	8.03±0.04^{d}	197.54±3.94^{a}	2.41±1.26^{a}	1.26±0.07^{a}
	Fufu	0.98±0.21^{a}	5.18±0.29^{a}	207.00±4.70^{b}	2.71±0.02^{a}	3.12±0.00^{c}
SIDW	Gari	1.47±0.06^{a}	7.47±0.01^{c}	296.70.±7.80^{b}	2.03±1.04^{a}	2.05±0.14^{b}
	Fufu	1.05±0.21^{a}	5.21±0.65^{a}	201.50.±8.83^{b}	3.44±0.00^{b}	4.76±0.34^{d}
L30572	Gari	1.65±0.00^{b}	7.89±0.10^{c}	164.54±3.84^{a}	8.64±0.74^{g}	2.64±0.00^{a}
	Fufu	2.82±0.03^{c}	5.79±1.01^{a}	174.30±7.45^{a}	7.18±0.34^{f}	4.45±0.00^{c}
	Lafun	3.84±1.84^{d}	8.02±0.11^{d}	173.43±3.40^{a}	7.56±0.07^{f}	5.99±0.00^{e}
LIL30572	Gari	1.53±0.18^{a}	7.54±1.08^{c}	15850±3.49^{a}	6.23±1.53^{e}	2.41±0.01^{a}
	Fufu	1.91±1.40^{b}	5.68±0.21^{a}	120.41±6.25^{a}	6.10±1.01^{e}	4.26±0.00^{c}
SIL30572	Gari	1.43±0.02^{a}	7.13±1.30^{c}	130.10±9.25^{a}	5.98±1.27^{d}	1.84±0.00^{a}
	Fufu	1.11±0.13^{a}	5.14±1.12^{a}	135.50±0.45^{a}	6.24±1.31^{e}	2.30±0.00^{a}

Means with the same superscript within a column are not significantly different ($p > 0.05$)

KD = Kpace Dzuru, LIKD = *L. bulgaricus* fermented, SIKD = *S. cerevisea* fermented, DW = Dan Warri, LIDW = *L. bulgaricus* fermented, SIDW = *S. cerevisea* fermented, L30572 = Improved variety, SIL30572 = *S. cerevisea* fermented, LIL30572 = *L. bulgaricus* fermented

Appendix XX: Mineral composition of microbial fermented cassava products of TME419, KG and TMS92/0326 varieties of Suleja samples in mgKg^{-1} DM

variety	products	Parameters						
		Zn	Mg	Na	K	Ca	Fe	P
TME419	Gari	405.49±4.22^{j}	2995.45±7.04^{b}	2359.10±6.18^{b}	2754.04±6.11^{c}	3366.40±7.35^{a}	1072.87±.3.87^{a}	55.33±2.00^{b}
	Fufu	407.24±2.95^{j}	3041.08±5.67^{a}	2590.46±5.12^{b}	2688.55±6.00^{c}	3421.00±6.05^{a}	1091.61±4.76^{a}	61.21±4.13^{a}
	Lafun	429.83±3.76^{h}	2885.40±6.95^{b}	2412.53±4.93^{b}	2621.45±7.38^{c}	2986.10±4.68^{b}	1063.45±2.75^{a}	49.00±4.83^{c}
LITME419	Gari	469.56±3.82^{c}	3075.46±5.87^{a}	2431.85±5.56^{b}	2883.53±6.30^{c}	3606.40±7.63^{a}	1240.66±4.73^{a}	58.98±4.10^{b}
	Fufu	464.04±3.19^{d}	3099.47±8.12^{a}	2878.33±5.62^{b}	3411.13±7.24^{b}	3591.10±7.21^{a}	1682.49±3.67^{a}	67.16±3.84^{a}
SITME419	Gari	494.07±4.00^{a}	3105.93±7.26^{a}	2442.05±5.32^{b}	3581.83±5.23^{b}	3530.70±8.53^{a}	1363.38±5.60^{a}	66.32±2.19^{a}
	Fufu	449.43±5.10^{t}	3141.45±6.59^{a}	3044.10±6.66^{a}	2844.13±6.09^{c}	3560.47±6.46^{a}	1172.71±6.00^{a}	65.90±4.13^{a}
KG	Gari	410.70±5.19^{i}	1150.92±5.32^{c}	2152.40±5.09^{b}	4151.94±8.42^{a}	1894.53±5.39^{c}	1211.34±3.22^{a}	39.51±4.48^{d}
	Fufu	409.36±3.91^{i}	1083.12±4.38^{c}	2103.96±6.49^{b}	3040.49±8.30^{b}	2003.93±5.92^{b}	1304.50±3.33^{a}	34.68±2.12^{d}
	Lafun	430.34±2.57^{g}	1003.80±6.31^{c}	2044.75±5.87^{b}	3004.04±9.21^{b}	1762.49±4.04^{c}	1003.36±3.61^{a}	41.82±3.24^{c}
LIKG	Gari	440.23±3.72^{t}	1247.42±4.37^{c}	2222.56±7.39^{b}	4581.22±6.73^{a}	2102.35±5.20^{b}	1243.64±4.78^{a}	42.92±4.10^{c}
	Fufu	424.63±3.02^{h}	1219.75±5.09^{c}	2341.61±5.02^{b}	3298.39±5.94^{b}	2272.10±5.41^{b}	1439.84±4.21^{a}	43.69±1.86^{c}
SIKG	Fufu	454.89±2.71^{e}	1284.39±6.94^{c}	2266.49±4.68^{b}	3490.94±6.74^{b}	2190.07±5.19^{b}	1568.48±7.24^{a}	43.00±3.03^{c}
	Gari	459.25±3.14^{e}	1250.04±5.54^{c}	2364.68±5.54^{b}	4642.24±6.39^{a}	2144.24±4.39^{b}	1230.26±6.90^{a}	42.08±2.14^{c}
TMS92/0326	Gari	349.72±3.17^{a}	1095.45±7.12^{c}	1906.84±4.39^{c}	3722.73±7.17^{b}	2760.62±5.05^{b}	1075.34±4.62^{a}	31.26±3.65^{d}
	Lafun	326.33±6.22^{a}	1120.39±4.21^{c}	1779.34±5.27^{c}	2893.24±5.08^{c}	2662.21±5.25^{b}	1228.00±3.18^{a}	33.87±4.43^{d}
	Fufu	382.30±5.20^{a}	1024.50±5.67^{c}	2411.25±3.34^{b}	3481.47±5.35^{b}	2810.55±7.12^{b}	1099.09±4.23^{a}	37.62±2.27^{d}
SITMS92/0326	Gari	374.55±4.02^{a}	3052.43±6.41^{a}	1993.48±6.35^{c}	4231.33±7.76^{a}	2871.43±5.84^{b}	1411.68±3.76^{a}	36.22±3.55^{d}
	Fufu	392.23±5.50^{a}	3084.37±4.57^{a}	2478.23±6.56^{b}	4004.13±5.34^{a}	2945.17±5.78^{b}	591.46±4.83^{b}	38.02±1.11^{d}
LITMS92/0326	Gari	402.13±4.30^{j}	3172.73±5.39^{a}	2040.56±5.84^{b}	4863.92±7.40^{a}	2832.14±6.35^{b}	613.78±5.31^{b}	34.77±4.12^{d}
	Fufu	416.20±3.89^{i}	3195.29±6.18^{a}	2521.82±6.82^{b}	3499.43±3.76^{b}	2896.61±6.92^{b}	913.35±4.52^{b}	38.27±2.86^{d}

Means with the same superscript within a column are not significantly different ($p > 0.05$)

TME419 = Improved vaiety, SITME419 = *S. cerevisea* fermented, LITME419 = *L. bulgaricus* fermented TME419 KG = Karimugi, LIKG = *L. bulgaricus* fermented, SIKG = *S. cerevisea* fermented, TMS92/0326 = Improved variety, SITMS = *S. cerevisea* fermented, LITMS = *L. bulgaricus* fermented

Appendix XXI: Mineral composition of microbial fermented cassava products of KB,BI and W varieties of Suleja samples in mgKg^{-1} DM

variety	products	Parameters						
		Zn	Mg	Na	K	Ca	Fe	P
KB	Gari	431.96±4.67^{g}	2815.45±7.23^{b}	2479.31±5.44^{b}	2654.84±3.93^{c}	3366.42±7.64^{a}	1075.46±.83^{a}	52.81±3.64^{b}
	Lafun	407.22±4.10^{j}	3001.12±7.20^{a}	2960.00±6.21^{b}	2688.45±6.19^{c}	3421.83±5.98^{a}	1228.51±2.87^{a}	49.99±4.56^{c}
	Fufu	429.87±5.17^{h}	2675.69±6.29^{b}	2512.23±7.37^{b}	2721.45±6.87^{c}	2986.61±7.11^{b}	1099.99±3.60^{a}	45.62±3.13^{c}
LIKB	Gari	469.49±3.87^{c}	3105.42±3.09^{a}	2561.87±5.37^{b}	2803.23±7.20^{c}	3566.34±8.32^{a}	1411.58±5.18^{a}	52.98±4.33^{b}
	Fufu	464.21±3.19^{d}	3099.53±5.90^{a}	2878.47±3.98^{b}	3871.19±5.29^{b}	3461.31±8.23^{a}	1281.44±4,17^{a}	48.42±4.41^{c}
SIKB	Gari	494.45±4.19^{a}	3125.47±6.33^{a}	2501.56±5.98b	3101.33±6.32^{b}	3530.47±5.84^{a}	1433.37±4.03^{a}	55.32±4.44^{b}
	Fufu	489.40±3.04^{b}	3141.48±7.30^{a}	2984.19±5.16^{b}	4004.11±5.22^{a}	3500.74±8.03^{a}	1113.43±3.9^{a}	50.32±1.98^{b}
BI	Gari	413.73±4.76i	1040.90±5.46^{c}	2702.47±8.30^{b}	4063.04±8.67^{a}	1894.45±4.17^{c}	924.36±3.00^{b}	45.62±3.13^{c}
	Fufu	409.16±3.48^{i}	1103.23±6.76^{c}	2105.66±6.35^{b}	3049.44±7.26^{b}	2093.63±8.30^{b}	896.19±2.44^{b}	46.98±2.25^{c}
	Lafun	390.45±2.19^{k}	1012.67±3.80^{c}	2024.71±6.33^{b}	3204.97±7.18^{b}	1762.31±7.34^{c}	784.80±3.11^{b}	45.40±1.51^{c}
LIBI	Gari	440.23±3.91^{f}	1297.29±6.39^{c}	282496±5.27^{b}	4681.32±7.19^{a}	2102.53±7.10^{b}	981.13±4.29^{a}	46.03±2.73^{c}
	Fufu	424.60±3.11^{h}	1269.86±4.17^{c}	2341.93±7.04^{b}	3228.38±4.61^{b}	2382.51±6.66^{b}	1004.04±3.97^{a}	47.24±2.46^{c}
SIBI	Gari	456.53±3.03^{e}	1304.20±3.70^{c}	2888.31±6.97^{b}	4170.93±5.33^{a}	2090.76±8.73^{b}	986.42±4.98^{b}	46.28±3.17^{c}
	Fufu	459.20±4.23^{k}	1250.64±4.51^{c}	2394.13±6.29^{b}	3542.25±7.39^{b}	2144.24±5.16^{b}	1080.08±6.65^{a}	47.62±2.42^{c}
W	Gari	349.76±3.00^{f}	1350.95±4.19c	1898.64±5.00^{c}	3122.47±7.63^{b}	2780.51±8.22^{b}	1122.22±5.09a	55.33±2.00^{b}
	Lafun	326.38±2.59^{j}	1183.32±7.12^{c}	1779.35±7.93^{c}	2773.25±6.10^{c}	2582.77±9.51^{b}	1091.81±4.37^{a}	61.21±4.13^{a}
	Fufu	382.34±3.27^{l}	1313.86±3.11^{c}	2411.23±6.35^{b}	3481.15±5.99^{b}	2790.45±8.79^{b}	1093.17±7.03^{a}	49.00±4.83^{c}
LIW	Fufu	394.55±4.20	1447.26±3.93^{c}	2842.88±7.35^{b}	3901.53±6.29^{b}	2961.45±6.05^{b}	1100.46±5.35^{a}	54.98±4.10^{b}
	Gari	392.39±2.86^{k}	1489.83±4.21^{c}	2478.36±5.33^{b}	3194.13±6.54^{b}	3095.81±6.97^{a}	1182.34±5.72^{a}	67.16±3.84^{a}
SIW	Gari	402.73±3.87^{j}	1564.24±6.77^{c}	2020.69±5.35^{b}	3963.09±6.19^{b}	2832.40±7.34^{b}	1163.84±3.90^{a}	66.32±2.19^{a}
	Fufu	416.22±4.00^{i}	1450.90±5.09^{c}	2762.43±7.10^{b}	4049.24±5.87^{a}	2864.10±5.82^{b}	1212.05±4.21^{a}	55.90±4.13^{b}

Means with the same superscript within a column are not significantly different ($p > 0.05$)

BI = Baba Iya, LIBI = *L. bulgaricus* fermented, SIBI = *S. cerevisea* fermented, KB = Kpace Bokun, LIKB = *L. bulgaricus* fermented, SIKB = *S. cerevisea* fermented, W = Wahabi, SIW = *S. cerevisea* fermented, LIW = *L. bulgaricus* fermented

Appendix XXII: Mineral compositions of microbial fermented cassava products of KD, DW and L30572 varieties of Suleja samples in mgKg^{-1} DM

variety	products	Parameters						
		Zn	Mg	Na	K	Ca	Fe	P
KD	Gari	433.46±5.21^{g}	1195.00±5.33^{c}	2372.10±6.29^{b}	3852.43±8.45^{b}	1904.50±7.00^{c}	972.02±6.98^{b}	39.51±4.48^{d}
	Fufu	407.±072.69^{jc}	1220.75±3.90^{c}	3100.40±6.20a	29420.02±7.56^{c}	1993.01±5.83^{c}	891.00±2.13^{b}	34.68±2.12^{d}
	Lafun	399.28±3.18^{k}	1004.50±3.56^{c}	2332.36±5.25^{b}	3531.10±7.38^{b}	1862.58±6.72^{c}	763.10±4.56^{b}	41.82±3.24^{c}
LIKD	Gari	469.08±3.01^{c}	2992.44±2.73^{b}	2443.07±6.98^{b}	4251.35±9.21^{a}	2103.75±5.92^{b}	1000.84±3.65^{b}	42.92±4.10^{c}
	Fufu	464.00±3.19^{b}	3009.29±5.91^{a}	3776.64±5.21^{a}	3116.58±6.21^{b}	2072.36±6.00^{b}	902.41±5.33^{b}	43.69±1.86^{c}
SIKD	Gari	494.74±3.93^{a}	3122.64±5.06^{a}	2541.53±5.32^{b}	4193.36±9.12^{a}	2090.83±4.13^{b}	1043.58±4.29^{a}	43.00±3.03^{c}
	Fufu	489.82±4.16^{b}	3195.55±6.83^{a}	3194.67±6.23^{a}	3189.47±8.70^{b}	2144.24±4.32^{b}	972.16±4,33^{b}	42.08±2.14^{c}
DW	Gari	433.17±5.11^{g}	2895.4±6.74^{b}	2152.49±6.73^{b}	4063.34±6.00^{a}	2660.75±6.50^{b}	801.73±3.68^{b}	31.26±3.65^{d}
	Lafun	409.36±3.87^{j}	3041.2±4,66^{a}	2103.6±8.12^{b}	3049.47±8.43^{b}	2682.10±.5.30^{b}	804.44±4.11^{b}	33.87±4.43^{d}
	Fufu	440.92±4.17^{t}	2885.44±7.39^{b}	2044.78±6.55^{b}	3204.83±6.20^{b}	2910.56±5.77^{b}	913.39±4.51^{b}	37.62±2.27^{d}
LIDW	Gari	440.12±3.62^{f}	3105.43±8.24^{a}	2222.73±7.05^{b}	4681.2±5.17^{a}	2741.24±6.45^{b}	1043.43±4.18^{a}	36.22±3.55^{d}
	Fufu	473.04±4.32^{e}	2969.22±.54^{b}	2341.90±7.16^{b}	3228.34±5.27^{b}	2795.11±5.61^{b}	1119.74±3.39^{a}	38.02±1.11^{d}
SIDW	Gari	454.93±4.05^{e}	3125.16±6.34^{a}	2208.1±4.85^{b}	4170.9±6.19^{a}	2832.28±7.52^{b}	1068.68±4.38^{a}	34.77±4.12^{d}
	Fufu	479.25±4.10^{c}	2991.42±4.28^{b}	2394.53±6.00^{b}	3542.56±5.39^{b}	3056.09±6.19^{a}	1230.76±3.54^{a}	38.00±2.86^{d}
L30572	Gari	433.75±3.54^{g}	1150.9±5.34^{c}	1898.6±5.10^{c}	3722.4±6.34^{b}	3366.49±5.92^{a}	1075.40±3.45^{a}	45.62±3.13^{c}
	Fufu	47.24±4.20i^{b}	1283.2±5.32^{c}	1975.3±4.56^{c}	2893.33±5.37^{c}	34210.16±6.22^{a}	1228.10±4.49^{a}	46.98±2.25^{c}
	Lafun	389.80±4.26^{a}	1123.8±4.12^{c}	1811.2±2.99^{c}	3481.12±5.44^{b}	2986.10±7.17^{b}	1099.29±4.29^{a}	45.40±1.51^{c}
LIL30572	Gari	469.76±4.29^{b}	1247.60±3.87^{c}	1962.84±4.29^{c}	4101.30±7.34^{a}	3566.40±8.44^{a}	1411.86±4.23^{a}	46.03±2.73^{c}
	Fufu	464.17±3.17^{b}	1319.27±7.23^{c}	2478.34±6.12^{b}	3054.21±6.34^{b}	3461.10±8.19^{a}	1591.44±3.76^{a}	47.24±2.46^{c}
SIL30572	Gari	494.08±2.76^{a}	1284.23±5.19^{c}	2000.52±5.38^{b}	4163.00±6.34^{a}	3530.70±6.43^{a}	1613.70±4.12^{a}	46.28±3.17^{c}
	Fufu	489.39±3.84^{b}	1350.71±5.07^{c}	2512.54±6.34^{b}	3049.43±5.20^{b}	3500.40±7.83^{a}	1313.55±3.14^{a}	47.62±2.42^{c}

Means with the different superscripts within a column are significantly different ($p < 0.05$)

L30572 = Improved vaiety, SIL30572 = *S. cerevisea* fermented, LIL30572 = *L. bulgaricus* fermented, KD = Kpace Dzuru, LIKD = *L. bulgaricus* fermented, SIKD = *S. cerevisea* fermented, DW=Dan Warri , LIDW= *L. bulgaricus* fermented, SIDW = *S. cerevisea* fermented

Appendix XXIII: Mineral compositions of microbial fermented cassava products of TME419, KG and TMS92/0326 varieties of Kontagora samples in mgKg^{-1} DM

variety		parametres						
		Zn	Mg	Na	K	Ca	Fe	P
TME419	Gari	413.71±4.54^{a}	1150.94±5.89^{c}	2152.43±7.65^{b}	3722.45±6.34^{b}	1894.75±7.62^{c}	812.26±4.32^{a}	37.51±4.48^{c}
	Fufu	409.66±5.21^{a}	1083.25±6.70^{c}	2103.62±6.34^{b}	2893.28±5.37^{c}	2003.98±6.96^{b}	946.19±5.02^{a}	34.68±2.12^{c}
	Lafun	398.02±3.04^{b}	1013.84±4.92^{c}	2044.76±6.34^{b}	2481.19±5.75^{c}	1762.67±4.87^{c}	1074.18±4.44^{a}	31.82±3.24^{d}
LITME419	Gari	440.23±5.07^{a}	1247.22±5.35^{c}	2222.17±6.44^{b}	4101.33±7.43^{a}	2102.60±7.24^{b}	981.17±3.28^{b}	42.92±4.10^{c}
	Fufu	424.16±4.03^{a}	1219.32±6.34^{c}	2341.46±5.00^{b}	3004.01±6.17^{b}	2072.01±7.43^{b}	1004.49±3.98^{a}	43.69±1.86^{c}
SITME419	Gari	454.87±5.63^{a}	1284.23±6.00^{c}	2208.31±6.03^{b}	4263.00±5.67^{a}	2090.00±6.79^{b}	996.58±3.30^{b}	43.00±3.03^{c}
	Fufu	459.24±4.23^{a}	1250.25±6.43^{c}	2394.53±5.86^{b}	3119.46±5.72^{b}	2144.54±5.86^{b}	1180.11±4.89^{a}	42.08±2.14^{c}
KG	Gari	433.00±5.15^{a}	1095.05±5.87^{c}	1898.26±4.76^{c}	2654.58±5.04^{c}	2760.10±5.12^{b}	682.07±3.17^{a}	31.26±3.65^{d}
	Fufu	407.12±3.28^{a}	1120.00±5.11^{c}	1779.33±5.23^{c}	2688.59±6.85^{c}	2662.41±6.00^{b}	791.13±6.10^{a}	33.87±4.43^{d}
	Lafun	429.83±4.00^{a}	1024.53±6.21^{c}	1411.22±4.35^{c}	2421.44±6.74^{c}	2430.50±5.99^{b}	1063.31±4.62^{a}	33.62±2.27^{d}
LIKG	Gari	469.00±3.45^{a}	1342.34±5.01^{c}	1962.18±6.03^{c}	2783.32±7.32^{c}	3141.74±8.15^{a}	710.76±3.87^{b}	32.28±2.55^{d}
	Fufu	434.83±4.31^{a}	1184.10±5.15^{c}	2478.23±6.32^{b}	2841.21±5.35^{c}	2795.51±5.26^{b}	882.40±5.38^{b}	38.02±1.11^{d}
SIKG	Fufu	464.13±3.19^{a}	1172.00±5.85^{c}	2000.25±5.90^{b}	3101.34±6.57^{b}	2832.34±5.06^{b}	863.38±3.81^{b}	34.77±4.12^{d}
	Gari	479.47±4.86^{a}	1905.20±4.16^{c}	2462.54±4.93^{b}	3016.25±6.35^{b}	2846.61±5.64^{b}	772.01±3.45^{b}	38.00±2.86^{d}
TMS92/0326	Gari	423.76±5.33^{a}	2995.47±5.35^{b}	2359.13±4.86^{b}	4063.01±4.22^{a}	2094.35±4.68^{b}	871.36±4.16^{b}	42.81±3.64^{c}
	Lafun	409.68±5.27^{a}	3041.60±6.78^{a}	3010.05±6.00^{a}	2989.14±5.67^{c}	1563.52±4.19^{c}	834.14±3.15^{b}	44.99±4.56^{c}
	Fufu	430.37±5.29^{a}	2885.33±6.22^{b}	2412.35±4.67^{b}	3204.00±5.39^{b}	1702.71±3.75^{c}	913.34±5.80^{b}	45.62±3.13^{c}
SITMS92/0326	Gari	440.47±3.00^{a}	3105.46±8.70^{a}	2381.82±5.21^{b}	4681.42±7.38^{a}	2202.17±5.21^{b}	1003.04±6.17^{a}	43.98±4.33^{c}
	Fufu	464.63±2.89^{a}	3099.62±7.11^{a}	2878.33±4.88^{b}	3228.39±5.18^{b}	2002.13±9.45^{b}	1139.54±4.23^{a}	48.42±4.41^{c}
LITMS92/0326	Gari	454.45±3.56^{a}	3125.43±7.56^{a}	2441.55±5.78^{b}	4170.53±6.82^{a}	2220.32±6.72^{b}	1068.84±3.76^{a}	54.32±4.44^{b}
	Fufu	489.26±4.88^{a}	3141.34±7.00^{a}	3004.12±6.36^{a}	3542.25±6.30^{b}	1904.22±4.88^{c}	1230.62±4.28^{a}	49.32±1.98^{c}

Means with the same superscript within a column are not significantly different ($p > 0.05$)

TME419 = Improved vaiety, SITME419 = *S. cerevisea* fermented, LITME419 = *L. bulgaricus* fermented, KG = Karimugi, LIKG = *L. bulgaricus* fermented, SIKG = *S. cerevisea* fermented, TMS92/0326= Improved vaiety, , LITMS92/0326 = *L. bulgaricus* fermented, SITMS92/0326 = *S. cerevisea* fermented

Appendix XXIV: Mineral composition of microbial fermented cassava products of KB, BI and W varieties of Kontagora samples in mgKg^{-1} DM

variety		parametres						
		Zn	Mg	Na	K	Ca	Fe	P
KB	Gari	349.17±3.76^{b}	2151.92±6.40^{b}	2119.33±5.27^{b}	3622.47±5.30^{b}	1994.55±3.98^{c}	1045.64±4.19^{a}	55.33±2.00^{b}
	Lafun	326.57±5.19^{b}	1303.32±4.87^{c}	2010.26±4.76^{b}	2733.28±5.22^{c}	1693.31±4.03^{c}	998.14±7.68^{b}	49.21±4.13^{c}
	Fufu	382.41±4.13^{b}	2213.90±5.84^{b}	2312.36±6.50^{b}	2941.71±5.61^{c}	1762.31±4.65^{c}	1099.96±5.11^{a}	49.00±4.83^{c}
LIKB	Gari	364.15±3.01^{b}	2247.49±6.41^{b}	2381.80±6.57^{b}	3841.33±6.24^{b}	2302.11±5.83^{b}	1311.83±4.53^{a}	60.98±4.10^{a}
	Fufu	392.58±2.63^{b}	2259.28±579^{b}	2558.36±7.12^{b}	3702.16±4.99^{b}	1972.1±6.32c	1151.44±3.76^{a}	57.16±3.84^{b}
SIKB	Gari	353.33±4.34^{b}	2284.00±6.04^{b}	2241.45±5.19^{b}	3963.34±7.43^{b}	2090.15±3.64^{b}	1113.7±4.22^{a}	56.32±2.19^{b}
	Fufu	416.42±2.89^{a}	2360.60±6.17^{b}	2644.16±4.55^{b}	3049.43±5.71^{b}	2144.23±6.86^{b}	1123.73±3.17^{a}	55.90±4.13^{b}
BI	Gari	433.63±4.77^{a}	1045.56±4.87^{c}	2002.14±6.63^{b}	2654.39±6.25^{c}	2760.61±5.67^{b}	981.64±6.02^{a}	39.51±4.48^{c}
	Fufu	437.23±3.54^{a}	1020.99±5.66^{c}	1973.66±4.12^{c}	2688.56±5.73^{c}	2662.17±4.77^{b}	1146.11±5.23^{a}	34.68±2.12^{c}
	Lafun	429.84±3.99^{a}	1004.15±3.69^{c}	1884.70±5.00^{c}	2721.47±5.60^{c}	2810.5±7.22^{b}	1174.80±3.56^{a}	32.52±3.24^{c}
LIBI	Gari	469.21±4.12^{a}	1112.40±5.62^{c}	2172.00±3.59^{b}	2783.02±3.55^{c}	2931.24±8.93^{b}	1224.81±4.34^{b}	42.92±4.10^{c}
	Fufu	464.34±4.66^{a}	1484.27±4.83^{c}	2141.75±5.27^{b}	3481.10±5.40^{b}	2793.41±7.16^{b}	1404.14±3.11^{a}	43.69±1.86^{c}
SIBI	Gari	484.12±3.33^{a}	1332.68±4.76^{c}	2208.21±6.00^{b}	4101.13±7.12^{a}	2982.47±6.81^{b}	1006.59±4.23^{b}	43.00±3.03^{c}
	Fufu	479.86±4.55^{a}	1135.65±4.16^{c}	2294.35±5.21^{b}	3004.15±7.32^{b}	2846.17±5.29^{b}	1280.41±4.87^{a}	42.08±2.14^{c}
W	Gari	413.47±3.20^{a}	2905.54±4.97^{b}	1908.62±5.65^{c}	4063.85±7.00^{a}	1944.75±5.98^{c}	1072.67±3.93^{b}	31.26±3.65^{d}
	Lafun	409.22±3.86^{a}	2041.12±5.74^{b}	1779.73±3.00^{c}	3049.45±6.66^{b}	1813.14±6.34^{c}	1091.67±6.21^{a}	30.07±4.43^{d}
	Fufu	430.67±4.07^{a}	2845.44±6.97^{b}	2311.52±4.95^{b}	3204.74±4.93^{b}	2062.85±7.23^{b}	1063.81±3.56^{a}	37.62±2.27^{d}
LIW	Fufu	440.42±5.18^{a}	3104.48.±3.21^{a}	2411.86±5.37^{b}	4681.20±8.21^{a}	2152.18±9.56^{b}	1110.88±3.42^{b}	36.22±3.55^{d}
	Gari	424.60±3.44^{a}	3129.77±6.34^{a}	2278.32±4.85^{b}	3228.34±4.89^{b}	2112.00±5.48^{b}	1260.45±4.20^{b}	35.02±1.11^{d}
SIW	Gari	434.48±4.29^{a}	3195.06±6.56^{a}	2000.52±6.20^{b}	4170.91±5.28^{a}	2290.22±6.52^{b}	1311.83±3.31^{b}	34.77±4.12^{d}
	Fufu	459.88±3.18^{a}	3001.40±7.36^{a}	2451.64±5.93^{b}	3542.24±6.74^{b}	2164.52±4.56^{b}	772.10±5.62^{b}	38.00±2.86^{d}

Means with the same superscript within a column are not significantly different ($p > 0.05$)

W = Wahabi, LIW = *L. bulgaricus* fermented, SIW = *S. cerevisea* fermented, KB=Kpace Bokun, LIKB= *L. bulgaricus* fermented, SIBK = *S. cerevisea* fermented, BI= Baba Iya , LIBI = *L. bulgaricus* fermented, SIBI = *S. cerevisea* fermented

Appendix XXV: Mineral compositions of microbial fermented cassava products of KD, DW and L30572 varieties of Kontagora Samples in mgKg^{-1}

Variety		parametres						
		Zn	Mg	Na	K	Ca	Fe	P
KD	Gari	349.67±3.22^{b}	3450.93±7.82^{a}	2359.51±5.19^{b}	3722.64±6.85^{b}	2760.19±7.20^{b}	801.63±3.56^{b}	52.81±3.64^{b}
	Fufu	326.90±2.97^{b}	3083.63±7.50^{a}	2010.05±4.67^{b}	2893.29±6.45^{c}	2662.41±4.89^{b}	804.64±4.00^{b}	46.99±4.56^{c}
	Lafun	312.39±3.76^{b}	2943.87±7.19^{b}	2412.3±6.28^{b}	3481.14±7,22^{b}	2310.56±6.29^{b}	913.39±2.72^{b}	45.22±3.13^{c}
LIKD	Gari	374.50±2.06^{b}	3547.00±6.26^{a}	2381.83±7.19^{b}	4101.36±6.38^{a}	2861.34±6.54^{b}	1243.64±3.14^{a}	52.98±4.33^{b}
	Fufu	392.30±4.82^{b}	3209.02±8.34^{a}	2878.35±5.18^{b}	3004.10±5.93^{b}	2795.41±5.92^{b}	1139.49±5.32^{a}	48.42±4.41^{c}
SIKD	Gari	402.03±4.41^{a}	3584.42±4.46^{a}	2341.54±5.09^{b}	4063.04±7.29^{a}	2832.94±6.16^{b}	1068.83±2.87^{a}	55.32±4.44^{b}
	Fufu	416.52±3.11^{a}	3250.40±6.93^{a}	2924.01±6.00^{b}	3004.45±7.23^{b}	2846.31±6.45^{b}	1230.23±2.16^{a}	50.32±1.98^{b}
DW	Gari	433.00±4,03^{a}	3095.21±7.10^{a}	2152.24±5.18^{b}	2654.00±5.19^{c}	1794.25±6.31^{c}	613.40±3.76^{a}	45.62±3.13^{c}
	Lafun	407.25±3.17^{a}	3010.35±7.21^{a}	1933.76±5.67^{c}	2688.5±40.17^{c}	2053.51±6.73^{b}	1228.33±3.23^{a}	43.98±2.25^{c}
	Fufu	429.84±4.85^{a}	3144.55±6.91^{a}	2044.74±3.45^{b}	2721.34±5.37^{c}	1762.08±5.65^{c}	591.49±4.16^{a}	45.40±1.51^{c}
LIDW	Gari	469.90±5.81^{a}	3352.4±6.85^{a}	2222.03±3.68^{b}	2783.52±6.54^{c}	2102.19±7.34^{b}	1411.85±3.11^{a}	46.03±2.73^{c}
	Fufu	464.14±5.33^{a}	3184.29±8.66^{a}	2341.11±5.21^{b}	3481.13±4.13^{b}	2072.36±6.74^{b}	1099.47±6.84^{b}	47.24±2.46^{c}
SIDW	Gari	474.47±3.06^{a}	3172.84±7.94^{a}	2208.10±6.42^{b}	4101.35±6.70^{a}	2090.00±6.87^{b}	1075.74±4.64^{b}	46.28±3.17^{c}
	Fufu	489.59±3.20^{a}	3195.00±8.67^{a}	2394.37±4.67^{b}	3004.19±8.99^{b}	2144.62±7.85^{b}	913.36±3.93^{b}	47.62±2.42^{c}c
L30572	Gari	423.74±2.93^{a}	1095.36±7.00^{c}	1898.69±3.99^{c}	4063.63±7.00^{a}	1894.25±4.16^{c}	750.44±4.33^{a}	55.33±2.00^{b}
	Fufu	409.43±3.76^{a}	1120.61±6.46^{c}	1779.31±3.76^{c}	3049.04±5.12^{b}	2003.10±5.28^{b}	591.12±5.36^{a}	61.21±4.13^{a}
	Lafun	430.65±4.67^{a}	1024.65±6.72^{c}	1551.26±4.85^{c}	3204.07±6.00^{b}	1762.31±5.42^{c}	1099.91±3.78^{a}	50.00±4.83^{b}
LIL30572	Gari	440.24±4.18^{a}	1162.34±5.85^{c}	1962.84±4.86^{c}	4681.25±7.68^{a}	2102.14±4.86^{b}	1411.84±4.62^{a}	55.98±4.10^{b}
	Fufu	424.56±4.16^{a}	1184.23±5.98^{c}	2478.25±6.85^{b}	3228.37±6.77^{b}	2072.15±7.67^{b}	1228.54±416^{b}	64.16±3.84^{a}
SIL30572	Gari	454.00±3.17^{a}	1172.11±7.39^{c}	2000.24±5.73^{b}	4170.98±7.00^{a}	2090.96±3.56^{b}	1022.76±4.62^{b}	56.32±2.19^{b}
	Fufu	459.21±3.82^{a}	1195.23±6.37^{c}	2492.47±4.86^{b}	3542.27±6.50^{b}	2144.24±5.24^{b}	913.33±3.54^{b}	63.90±4.13^{a}

Means with the different superscript within a column are significantly different ($p < 0.05$)

KD = Kpace Dzuru, LIKD = *L. bulgaricus* fermented, SIKD = *S. cerevisea* fermented, DW=Dan Warri, LIDW= *L. bulgaricus* fermented, SIDW = *S. cerevisea* fermented, L30572= Improved vaiety, , LIL30572 = *L. bulgaricus* fermented, SIL30572 = *S. cerevisea* fermented

Appendix XXVI: Mineral compositions of microbial fermented cassava products of TME419, KG and TMS92/0326 of Bida Samples in $mgKg^{-1}$

Variety		Parameters						
		Zn		Na	K	Ca	Fe	P
TME419	Gari	433.30±3.52^{b}	1095.04±5.77^{c}	1688.69±4.78^{c}	2654.20±6.09^{d}	2064.52±6.10^{b}	1073.47±4.67^{a}	45.62±3.13^{c}
	Fufu	447.23±4.12^{b}	1120.54±5.94^{c}	1079.38±5.04^{c}	2888.53±5.99^{d}	2133.17±5.83^{b}	1102.43±3.90^{a}	46.98±2.25^{c}
	Lafun	429.81±3.71^{b}	1024.52±5.83^{c}	1481.46±5.07^{c}	2521.45±5.87^{d}	1812.76±4.97^{c}	1012.64.±5.06^{a}	40.40±1.51^{c}
LITME419	Gari	469.00±4.00^{b}	1452.40±7.72^{c}	1862.80±6.93^{c}	2783.78±6.73^{d}	2142.14±5.89^{b}	1200.45±4.99^{a}	47.03±2.74^{c}
	Fufu	464.21±2.56^{b}	1984.84±5.03^{c}	1478.52±4.83^{c}	3481.33±7.84^{c}	2192.10±6.90^{b}	1124.66±5.07^{a}	47.24±2.46^{c}
SITME419	Gari	474.06±5.11^{b}	2172.19±5.67^{b}	2000.29±8.60^{b}	3701.33±7.42^{c}	2240.24±5.19^{b}	1246.17±4.86^{a}	46.28±3.17^{c}
	Fufu	459.00±3.55^{b}	3195.29±5.96^{a}	1262.74±6.09^{c}	3004.19±6.36^{c}	2204.2±5.96^{b}	1174.80±4.33^{a}	47.62±2.42^{c}
KG	Gari	413.75±4.62^{b}	2895.64±7.11^{b}	2679.61±7.53^{b}	3763.00±7.16^{c}	1894.50±5.04^{c}	981.15±3.59b	55.33±2.00^{b}
	Fufu	409.64±4.00b	3041.60±8.62^{a}	3010.00±8.11^{b}	3049.43±6.54^{c}	2103.73±5.76^{b}	1004.64±2.98^{a}	61.21±4.13^{a}
	Lafun	370.50±3.84^{c}	2965.69±6.92^{b}	2412.32±7.15^{b}	3204.46±6.08^{c}	1762.01±4.59^{c}	796.33±22.73^{a}	49.00±4.83^{c}
LIKG	Gari	440.25±4.30^{b}	3105.84±7.91^{a}	2381.89±7.84^{b}	3881.87±7.34^{c}	2162.16±5.33^{b}	1080.01±4.26^{a}	54.98±4.10^{b}
	Fufu	424.60±2.99^{b}	3099.26±6.08^{a}	3338.34±8.22^{a}	3228.53±6.25^{c}	2367.36±6.43^{b}	1102.18±4.67^{a}	67.16±3.84^{a}
SIKG	Fufu	454.39±4.04^{b}	3125.86±7.54^{a}	3361.50±7.86^{a}	3170.90±5.86^{c}	2090.76±4.97^{b}	1091.24±4.65^{a}	66.32±2.19^{a}
	gari	459.20±6.11^{b}	3141.48±8.42^{a}	2734.19±8.00^{b}	3842.86±6.11^{c}	2262.29±5.71^{b}	1163.87±3.92^{a}	55.90±4.13^{b}
TMS92/0326	Gari	569.7I±4.32^{a}	1170.91±7.93^{c}	2152.4±5.86^{b}	3722.44±6.53^{c}	2810.69±6.10^{b}	710.84±3.87b	39.51±4.48^{d}
	Lafun	396.21±5.17^{c}	1113.96±6.34^{c}	1903.17±6..95^{c}	2893.52±6.04^{d}	2123.51±6.00^{b}	682.39±4.71^{b}	34.68±2.12^{d}
	Fufu	382.33±4.20^{c}	1213.86±7.89^{c}	2044.76±7.03^{b}	3481.01±6.82^{c}	2810.35±5.87^{b}	883.58±3.22^{b}	41.82±3.24^{c}
SITMS92/0326	Gari	584.55±7.11^{a}	1247.44±6.71^{c}	2222.00±6.90^{b}	4201.35±8.46^{b}	2901.40±5.65^{b}	754.13±3.63^{b}	42.92±4.10^{c}
	Fufu	392.30±3.67^{c}	1279.20±6.23^{c}	2341.78±6.83^{b}	3514.00±7.22^{c}	3025.31±7.66a	961.71±4.51^{b}	43.69±1.86^{c}
LITMS92/0326	Gari	572.34±3.89^{a}	1284.23±6.35^{c}	2288.46±6.26^{b}	3983.46±7.01^{c}	3042.83±8.76^{a}	844.39±5.60^{b}	43.00±3.03^{c}
	Fufu	416.22±4.55^{b}	1250.34±8.43^{c}	2394.36±7.02^{b}	3609.64±6.26^{c}	2986.31±4.39^{b}	913.53±4.40^{b}	42.08±2.14^{c}

Means with the same superscript within a column are not significantly different ($p > 0.05$)

TME419 = Improved vaiety, SITME419 = *S. cerevisea* fermented, LITME419 = *L. bulgaricus* fermented, KG = Karimugi, LIKG = *L. bulgaricus* fermented, SIKG = *S. cerevisea* fermented, TMS92/0326= Improved vaiety, , LITMS92/0326 = *L. bulgaricus*fermented, SITMS92/0326 = *S. cerevisea* fermented

Appendix XXVII: Mineral compositions of microbial fermented cassava products of KB, BI and W varieties of Bida Samples in $mgKg^{-1}$

Variety	product	parametres						
		Zn	Mg	Na	K	Ca	Fe	P
KB	Gari	513.00±5.33^{ab}	1142.43±8.15^{c}	1898.67±5.86^{c}	2654.19±6.59^{d}	2860.44±6.18^{b}	1243.40±4.02^{a}	31.26±3.65^{d}
	Lafun	347.24±2.87^{c}	1002.11±7.03^{c}	1779.94±4.99^{c}	2618.50±5.87^{d}	2472.14±5.06^{b}	1009.64±3.97^{a}	33.87±4.43^{d}
	Fufu	429.81±3.22b	1024.55±6.89^{c}	2411.52±6.45^{b}	2721.04±5.10^{d}	2880.5±4.89^{b}	1068.80±4.67^{a}	37.62±2.27^{d}
LIKB	Gari	539.99±3.88^{a}	2002.84±6.71^{b}	1962.84±5.42^{c}	2783.28±4.97^{d}	2981.45±5.73^{b}	1410.66±4.14^{a}	36.22±3.55^{d}
	Fufu	464.18±3.42^{b}	1974.44±55.82^{c}	2478.22±7.35^{b}	3481.10±6.73^{c}	2895.18±4.76^{b}	1195.23±4.67^{a}	38.02±1.11^{d}
SIKB	Gari	554.33±4.20^{a}	1272.57±7.46^{c}	2040.67±4.79^{b}	3011.38±6.77^{c}	2996.47±5.00^{b}	1236.13±5.02^{a}	34.77±4.12^{d}
	Fufu	479.46±4.69^{b}	1195.62±5.69^{c}	2482.45±7.34^{b}	3004.51±6.34^{c}	2846.21±5.68^{b}	1219.92±4.70^{a}	38.00±2.86^{d}
BI	Gari	413.74±3.92^{b}	2995.49±6.85^{b}	2499.18±8.46^{b}	3893.70±7.06^{c}	3366.84±8.20^{a}	1411.48±4.65^{a}	52.81±3.64^{b}
	Fufu	409.60±5.30^{b}	3141.12±8.32^{a}	3130.83±8.91^{a}	3149.48±7.09^{c}	3421.64±8.93^{a}	891.76±3.89^{b}	49.99±4.56^{c}
	Lafun	380/59±5.22^{c}	2683.55±7.08^{b}	2212.46±7.06^{b}	3204.60±6.57^{c}	2990.48±6.54^{b}	613.73±3.00^{b}	45.62±3.13^{c}
LIBI	Gari	440.29±4.19^{b}	3105.54±5.90^{a}	2571.68±6.23^{b}	3981.24±7.00^{c}	3566.48±7.64^{a}	1553.34±4.39^{a}	52.98±4.33^{b}
	Fufu	424.47±6/08^{b}	3199.85±6.15^{a}	3278.73±8.56^{a}	3228.39±7.04^{c}	3461.64±6.45^{a}	1102.27±5.05^{a}	48.42±4.41^{c}
SIBI	Gari	454.30±4.00^{b}	3125.40±5.07^{a}	25341.57±6.38^{b}	4020.94±8.32^{b}	3530.70±7.09^{a}	1602.41±5.32^{a}	55.32±4.44^{b}
	Fufu	459.25±4.37^{b}	3161.64±8.76^{a}	3044.13±8.64^{a}	3542.56±7.05^{c}	3500.54±6.97^{a}	1200.00±5.91^{a}	50.32±1.98^{b}
W	Gari	349.71±4.61^{c}	1051.58±6.89^{c}	2192.47±7.30^{b}	3722.44±5.78^{c}	2194.58±4.72^{b}	1344.48±4.63^{a}	45.62±3.13^{c}
	Lafun	306.03±4.90^{c}	1063.93±7.41c	2143.00±5.64^{b}	2893.24±5.92^{d}	1773.51±3.90^{c}	1046.12±4.38^{a}	46.98±2.25^{c}
	Fufu	382.33±5.00^{c}	1103.81±8.31^{c}	2044.70±6.00^{b}	3281.10±6.89^{c}	1822.81±5.00^{c}	1204.84±4.76^{a}	45.40±1.51^{c}
LIW	Fufu	394.55±4.16^{c}	1247.25±6.98^{c}	2222.00±5.26^{b}	4101.38±8.08^{b}	2102.61±6.43^{b}	1383.39±4.44^{a}	46.03±2.73^{c}
	Gari	362.36±3.33^{c}	1219.72±5.88^{c}	2341.60±6.08^{b}	4004.18±6.74^{b}	2072.31±7.44^{b}	1454.94±5.00^{a}	47.24±2.46^{c}
SIW	Gari	352.35±4.73^{c}	1484.49±6.09^{c}	1708.14±5.85^{c}	4164.04±8.23^{b}	2350.45±4.91^{b}	1391.22±4.31^{a}	46.28±3.17^{c}
	Fufu	416.24±4.19^{b}	1250.48±7.46^{c}	2394.45±5.76^{b}	3449.54±6.43^{c}	2024.27±4.87^{b}	1240.18±4.29^{a}	47.62±2.42^{c}

Means with the same superscript within a column are not significantly different ($p > 0.05$)

W = Wahabi, LIW = *L. bulgaricus* fermented, SIW = *S. cerevisea* fermented, KB=KpaceBokun, LIKB= *L. bulgaricus* fermented, SIBK = *S. cerevisea* fermented, BI = Baba Iya, LIBI = *L. bulgaricus* fermented,SIBI = *S. cerevisea* fermented

Appendix XXVIII: Mineral compositions of microbial fermented cassava products of KD, DW and L30572 of Bida Samples in $mgKg^{-1}$

variety		parametres						
		Zn		Na	K	Ca	Fe	P
KD	Gari	433.00±3.09^{b}	1295.19±8.16^{c}	1898.64±4.8^{c}	3522.46±6.9^{c}	3410.71±7.1^{a}	1072.45±4.92^{a}	55.33±2.00^{b}
	Fufu	407.15±3.67^{b}	1120.65±8.03^{c}	1779.36±5.6^{c}	2893.72±4.8^{d}	2662.45±5.7^{b}	1091.22±4.61^{a}	61.21±4.13^{a}
	Lafun	389.87±4.45^{c}	1024.52±8.67^{c}	1311.77±5.8^{c}	3111.65±6.8^{c}	2510.58±5.9^{b}	963.01±3.73^{b}	49.00±4.83^{c}
LIKD	Gari	469.00±5.67^{b}	1822.44±7.61^{c}	1962.85±6.2^{c}	3761.34±5.9^{c}	3741.73±7.5^{a}	1200.04±4.60^{a}	54.98±4.10^{b}
	Fufu	434.90±3.67^{b}	1384.61±6.18^{c}	2118.29±7.3^{b}	3004.01±5.7^{c}	2795.10±6.4^{b}	1282.58±4.20^{a}	67.16±3.84^{a}
SIKD	Gari	494.68±3.75^{b}	1562.28±5.88^{c}	2160.52±6.3^{b}	3923.59±7.0^{c}	3969.41±8.9^{a}	1373.80±4.90^{a}	66.32±2.19^{a}
	Fufu	449.45±4.31^{b}	1295.50±7.33^{c}	2092.14±5.9^{b}	3219.64±6.0^{c}	2846.41±4.9^{b}	1212.14±3.94^{a}	55.90±4.13^{b}
DW	Gari	433.74±4.57^{b}	3065.45±7.46^{a}	2359.11±6.0^{b}	2594.16±4.8^{d}	2850.15±5.3^{b}	801.32±3.16^{b}	39.51±4.48^{d}
	Lafun	419.61±4.87^{b}	2941.53±5.49^{b}	2220.35±6.9^{b}	2608.85±4.9^{d}	2562.18±4.9^{b}	713.19±3.39^{b}	34.68±2.12^{d}
	Fufu	430.41±5.83^{b}	2885.21±5.34^{b}	2412.34±5.8^{b}	2721.34±5.3^{d}	2850.57±4.6^{b}	933.24±3.47^{b}	41.82±3.24^{c}
LIDW	Gari	440.25±4/50^{b}	3105.40±5.77^{a}	2401.83±5.7^{b}	2483.20±5.3^{d}	2943.42±5.3^{b}	1043.66±3.54^{a}	42.92±4.10^{c}
	Fufu	432.60±2.98^{b}	3099.00±48.00^{a}	2878.53±6.2^{b}	2881.21±5.5^{d}	2945.10±5.2^{b}	1139.44±4.87^{a}	43.69±1.86^{c}
SIDW	Gari	454.00±4.37^{b}	3125.54±7.45^{a}	2341.50±5.7^{b}	3101.30±5.6^{c}	3002.44±7.0^{c}	1148.38±4.95^{a}	43.00±3.03^{c}
	Fufu	459.28±4.00^{b}	3141.43±7.37^{a}	3044.00±7.9^{a}	3004.41±6.2^{c}	2896.31±5.1^{b}	1230.63±5.10^{a}	42.08±2.14c
L30572	Gari	439.09±3.87^{b}	1150.89±6.72^{c}	2012.44±6.3^{b}	5023.53±9.0^{a}	3366.74±6.6^{a}	1075.45±4.26^{a}	31.26±3.65^{d}
	Fufu	407.26±5.22^{b}	1083.45±5.67^{c}	2103.67±6.4^{b}	3219.46±6.9^{c}	3421.56±6.3^{a}	1118.91±4.69^{a}	33.87±4.43^{d}
	Lafun	419.80±5.02^{b}	1013.38±6.12^{c}	2184.83±6.3^{b}	3205.63±6.3^{c}	3006.17±6.8^{a}	1019.50±4.83^{a}	37.62±2.27^{d}
LIL30572	Gari	469.76±4.72^{b}	1247.42±8.22^{c}	2222.63±5.8^{b}	5201.09±8.9^{a}	3966.84±8.2^{a}	1361.87±5.21^{a}	36.22±3.55^{d}
	Fufu	464.67±4.48^{b}	1219.23±6.34^{c}	2341.90±6.1^{b}	3448.3±6.19^{c}	3461.51±7.3^{a}	1181.55±4.78^{a}	38.02±1.11^{d}
SIL30572	Gari	494.27±3.93^{b}	1284.246±5.11^{c}	2248.71±5.48^{b}	5170.94±9.0^{a}	3530.73±7.4a	1213.72±4.51^{a}	34.77±4.12^{d}
	Fufu	489.47±4.19^{b}	1250.00±6.34^{c}	2394.33± 4.9^{b}	3621.42±8.43^{c}	3500.46±7.89^{a}	1083.33±4.11^{a}	38.00±2.86^{d}

Means with the same superscript within a column are not significantly different ($p > 0.05$)

KD = Kpace Dzuru, LIKD = *L. bulgaricus* fermented, SIKD = *S. cerevisea* fermented, DW=Dan Warri, LIDW= *L. bulgaricus* fermented, SIDW = *S. cerevisea* fermented, L30572 = Improved variety, LIL30572= *L. bulgaricus* fermented, SIL30572I = *S. cerevisea* fermented