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Review

Improvement in the nutritive quality of cassava and its by-products through microbial fermentation

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A review of the extent of fermentation of cassava and its by-products was made in order to highlight the role played by fermentation on the bio-conversion of cassava and cassava by-products for improved nutrient quality. The reasons for cassava products fermentation mentioned were 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; impartation of good aroma, flavour and texture; preservation of the fermented products and decrease in cooking time and fuel requirement. The choice of the fermentation methods that have been employed was the next topic of this article with a dividing line drawn between the two most popular fermentation methods – submerged/liquid substrate fermentation and solid substrate fermentation in which the balance is greatly tilted in favour of the latter, especially in the developing countries because of its relatively low cost, ease of adaptability of local conditions and technologies, little or no effluent generation and a much reduced rate of environmental pollution. The array of some cassava products that have been fermented with their varied rate of success in terms of nutrient enhancement from diverse cultures and background together with animal trials conducted to validate the *in vitro* nutrient enhancement of these products was also highlighted.

Key words: Nutritive quality, fermentation methods, cassava, by-products.

INTRODUCTION

The nutritive role played by cassava in human and livestock nutrition especially in Africa has ever been on the increase since the pioneer work on its utilization by Oyenuga and Opeke (1957). To underline this fact, the continent accounts for more than 90% of the global cassava production in 2004 (FAO, 2005) with Nigeria contributing 38.4 million metric tones and coming up from the third position behind Brazil and Zaire in the Eighties to being the largest producer of cassava in the world today. Cassava is reported of having the capacity of yielding more than thirteen times as much energy per hectare than maize or guinea corn (Oyenuga, 1961; Hahn et al., 1973; Oke, 1978). Cassava is a very cheap source of carbohydrate and is the main carbohydrate source in the diet of the teeming population of the third world countries where it is largely grown. In fact, Banjoko et al. (2008) posited that cassava is a supplementary staple food of more than 200 million Africans aside from its use as livestock feed particularly for monogastrics.

The use of cassava and its by-products has enjoyed widespread patronage in the nutrition of many livestock species namely: swine (Akinfala and Tewe, 2001; Iyayi and Tewe, 1986; Obioha and Anikwe, 1982; Oyenuga, 1961), rabbit (Omole and Sonaiya, 1981; Eshiet et al., 1980), poultry (Fetuga and Oluyemi, 1976; Enriquez and Ross, 1972 and 1967) and small ruminants (Belewu and Jimoh, 2004). The research searchlight beamed on cassava and its products for about five decades now has continued to glow unabated. We are to appreciate the new uses to which cassava is being put with corresponding by-products that usually go along with the discovery of each use. For example, Aro et al. (2008) reported five of such by-products released to the environment by a local cassava starch processing factory.

Other authors have also reported such cassava by-products from many areas (Bakrie, 2002; Cereda and Mattos, 1996; Tewe, 1996; Hutagalung et al., 1974). The nutritional importance of cassava and its by products is

however constrained by a number of factors. According to Iyayi et al. (1997), the utilization of most of the agro-industrial by-products is plagued by their high level of structurally indigestible carbohydrates often designated as non-starch polysaccharide (NSP). These NSP include cellulose, hemicellulose, pectin and lignin. Cassava by-products are also reputedly high in anti-nutrients like hydrogen cyanide (HCN) polyphenols (tannins) and phytate and low in protein (Akpan and Ikenebomeh, 1995). The fallout of these constraints on the animals include low digestibility, poor feed intake and reduced animal performance (Alawa and Amadi, 1990; Adegbola and Oduozo, 1992).

Concerted efforts have been made to either eliminate or reduced these constraints to cassava and its by-products utilization. Such efforts include sun-drying (Odukwe, 1994), oven-drying, treatment with chemical preparation (Jackson,1997; Adebowale, 1985), steeping/ retting or soaking in water, cooking (Okeke et al.,1985) and wetting/moistening (Badbury, 2004). All these efforts are with varied level of success, cost effectiveness and adaptability to local technologies. Fermentation, either naturally or with selected microbial inoculums has also been extensively used to enhance the nutrient potentials of cassava and its by-products both for human and livestock consumption.

The extent or scope of bioconversion of cassava and its by-products through fermentation, considered as the oldest known form of food biotechnology (Borgstrom, 1968) is the crux of this review article.

THE NEED FOR FERMENTATION OF CASSAVA AND CASSAVA BY-PRODUCTS

Fermentation of cassava and its by-products automatically qualifies such products as fermented foodstuffs, which according to Campbell-Platt (1994) are defined as animal or plant tissues subjected to the action of micro-organisms and/enzymes to give desirable biochemical changes and significant modification of food quality. The general reasons advanced for such fermentation as outlined by Steinkraus (1995) are as listed below:

(a). Detoxification of food/feed anti-nutrients during the process of fermentation.
(b). Biological enrichment of food substrates with proteins, essential amino acids, essential fatty acids and vitamins.
(c). Enrichment of the fermented products through the impartation of an array of aroma, flavours and textures.
(d). Preservation of the fermented products through the production of lactic acid, acetic acid, alcohol and alkali in the substrate as a result of fermentation.
(e). Decrease in cooking time and fuel requirements.

All the reasons outlined above have been achieved through the fermentation of cassava and cassava by-products. Research works of Nwafor and Ejukonemu (2004), Kompiang et al. (1994), Sukara and Doelle (1988), Brook et al. (1969) and Gray and Abou-El-Seoud (1966) gave clear evidence of protein enrichment of cassava products through fermentation. Akindahunsi et al. (1999) and Akinrele et al. (1962) reported on the flavour-enriching ability of microorganisms in the fermentation of cassava pulp and its conversion to a popular starchy staple (gari) consumed extensively in Nigeria. The detoxification of anti-nutrients in cassava especially of hydrogen cyanide tannins and phytates was reported by Oboh and Akindahunsi (2003) and Hahn (1992) while the safety and preservation of the final fermented products such as gari and lafun in Nigeria through acidification and dehydration was reported by Oboh et al. (2000), Akindahunsi et al. (1999) and Opadokun, 1978.

CHOICE OF FERMENTATION METHODS FOR CASSAVA AND ITS BY-PRODUCTS

In the fermentation of cassava and its by-products, a choice has to be made between two popular fermentation techniques, namely: the liquid substrate or submerged fermentation technique and the solid substrate fermentation. Balagopalan et al. (2002) described the submerged fermentation technique as the one in which water is always in a free state while food nutrients in the form of carbon, nitrogen, phosphorus and others are in a suspended or dissolved state. These authors also stated certain conditions that must be met in order to ensure a successful fermentation.

These include the strict observance of aseptic inoculation of microorganisms which could only be economically feasible when done on an industrial scale i.e. its application is yet to be suited to the traditional village setting where the bulk of the producers of cassava and its products are domiciled. Aside from the requirement of a sterile environment for the operation of submerged fermentation, enzymatic or acid treatment of starch is necessary when yeasts are to be used as the microbial inoculums, also recovery of the cell mass could be tedious and might involve further processes like centrifugation/ultra-filtration before separation of cell biomass could be achieved (Balagopalan et al., 2002).

Despite the shortcomings to the technique of submerged fermentation enumerated above, Reade and Gregory (1975), Gregory (1977) and Gregory et al. (1977) reported several works on submerged fermentation of cassava in Canada using a combination of high temperature and thermo-tolerant fungi to ensure bioconversion and protein enrichment of cassava for livestock feeds. Muindi and Hanssen (1981b) and Mikami et al. (1982) also reported on their study on liquid substrate fermentation using two strains of acidophilic fungi: *Trichoderma harzianum* and *Cephalosporium eichhorniae* respectively. Protein enrichment of the biomass recovered from these submerged fermentations as reported

Table 1. Comparison between liquid and solid substrate fermentations.

Factor	Liquid substrate fermentation	Solid substrate fermentation
Substrates.	Soluble substrates (sugars)	Polymer insoluble substrates: starch, cellulose, pectins, lignin
Aseptic conditions	Heat sterilization and aseptic control	Vapour treatment, non-sterile conditions
Water	High volumes of water consumed and effluents discarded	Limited consumption of water, low A_w. No effluent
Metabolic heating	Easy control of temperature	Low heat transfer capacity
Aeration(O_2)	Limitation of soluble O_2. High level of air required	Easy aeration and high surface exchange air/substrate
pH control	Easy pH control	Buffered solid substrates
Mechanical agitation	Good homogenization	Static conditions preferred
Scale up	Industrial equipment available	Need for engineering and new designed equipment
Inoculation	Easy inoculation, continuous process	Spore inoculation, batch process
Contamination	Risk of contamination for single strain bacteria	Risk of contamination for low rate growth fungi
Energetic consideration	High energy consuming	Low energy consuming
Volume of equipment	High volumes and high cost technology	Low volumes and low cost of equipment
Effluent and pollution.	High volumes of polluting effluents	No effluents, less pollution
Concentration/products	30-80g/l	100-300g/l

Source: Raimbault (1998).

by these authors was quite substantial: 37.6% crude protein on dry matter basis (from 2.4% in the untreated cassava root meal) and 41% crude protein for *T. harzianum* and *C. eichhorniae,* respectively.

The solid substrate fermentation (SSF), on the other hand, is a bio-system consisting of a solid, porous, water-absorbing matrix, which can either be biodegradable or not, of relatively high water activity on solid/gas interface in which air mixture of oxygen with other gases freely circulate under a relatively low pressure within the fermenting substrate/mash (Raimbault, 1998). Other conditions to be fulfilled by a solid substrate bio-system according to the author are that the solid/gas interface should be a good habitat for growth and fast development of specific culture of moulds, yeasts or bacteria either in pure or mixed cultures. Also, the mechanical properties of the solid matrix should be such that could withstand compression or gentle stirring and that the solid matrix should not be contaminated by microbial inhibitors and should contain or be able to absorb microbial nutrients (carbohydrates, nitrogen and mineral salts). Excerpts from a review written by Raimbault (1998) on the comparison between liquid and solid substrate fermentation is as presented in Table 1.

From the table and judging from the factors considered, the choice of which fermentation technique to use is tilted in favour of SSF especially in developing countries where the technical-know-how and capital outlay needed to successfully establish and maintain a liquid substrate bio system are grossly inadequate if not completely lacking. These views are succinctly put forward by Brook et al. (1969) who concluded that besides reduction in the fermenters volume vis-à-vis liquid substrate fermentation, other advantages of SSF include: simplicity, ease of adaptation to rural conditions, elimination of foaming and a reduced cost of the final products.

THE ARRAY OF CASSAVA PRODUCTS AVAILABLE FOR FERMENTATION

Some of the major cassava products that have been extensively fermented in various forms are presented under the subtitles below. Efforts have also been made to review some of the trials /studies in which these products are used.

Cassava roots

The thrust of fermentation of cassava roots is to increase the protein content from a lowly 2.0% on the average to near or above the critical 7.0% crude protein content. Several SSF techniques have been employed to achieve this. Varghese et al. (1976) experimented with the direct fermentation of cassava root alone with *Aspergillus neurospora* and *Rhizopus* and achieved a 3% increase in protein values using nitrogenous supplements like pineapple bran and chicken manure.

The principle underlying a procedure for cassava flour enrichment through SSF was reported by Raimbault et al. (1977). This procedure led to protein enrichment of cassava flour from 1% crude protein content to between 18-20%, an enhancement of between 1700-1900% in just 30 h. Table 2 shows the result of this prodigious enrichment. Raimbault et al. (1985) investigated the possibility of using fungal strains from America, Africa and Asia as

Table 2. Protein enrichment of cassava by solid-state fermentation.

Initial substrate	Composition
Cassava flour[1]	100 g
$(NH_4)_2SO_4$	9 g
Urea	2.7 g
KH_2PO_4	5 g
Water	100 - 120 g
Optimal growth conditions	
T^o 35 - 40 °C; initial pH: 3.5 Inoculum: 2 x 10^7 spores/g of flour Incubation time: 30 h	
Composition of the product	
Protein[2]	18 - 20%
Residual sugars[3]	25 - 30%
Water	63%

[1]Carbohydrates: 90%; protein: 1%; water: 30 - 35%.
[2]Determined by the Lowry method.
[3]Determined by enzymatic hydrolysis (amyloglucosidase) and

inoculums in solid substrate fermentation trials with cassava root meal. Their results revealed protein enhancement ranging between 10.9-16.5%. Kompiang et al. (1994) reported an increase in protein content of sliced cassava roots from 3% to 18-42% through SSF with *Aspergillus niger*, urea and mineral salts of the following composition: urea (16.7 g), $(NH_4)_2SO_4$ (32.2 g), NaH_2PO_4 (62.5 g), $MgSO_4$ (2.08 g), KCl (0.63 g) and $FeSO_4$ (0.31 g). Two grammes of *A. niger* was added to each kilogramme of the substrate-nutrient mixture.

The field of microbiological research has also been extended towards the isolation of microbial strains endowed with the ability to degrade starch without prior gelatinization. It has been observed that microorganisms have preference for gelatinized starch as a fermentable substrate and feeding of gelatinized substrates to microorganisms calls for expenditure on energy required for the initial gelatinization. Abe et al. (1988) and Bergmann et al. (1988) conducted trials with fungi that are able to produce enzymes capable of degrading raw or crude starch, thus helping to safe cost hitherto expended on initial gelatinization as a prelude to fermentation of starchy substrates. In the same vein, Soccol (1992) and Soccol et al. (1994) reported on an extensive research on the fungi of the *Rhizopus* group and their ability to degrade crude starch granules for protein enrichment in the SSF techniques.

Cassava peels

Cassava peels are wastes generated as a result of mechanical removal of the two outer coverings of cassava roots prior to its subsequent processing to other cassava products like starch, flour, chips, “gari,” “fufu” etc. Aro et al. (2008) and Tewe (1996) gave the proportion of peel in a whole tuber in a factory-processed and hand-processed cassava peels as 5 and 8%, respectively. Most of these peels are left to rot away with unwholesome consequences on the environment in spite of their great nutritional potentials especially for livestock feeding. The constraints to their use in livestock nutrition are their high fibre content, low calorific value and their heavy loads of anti-nutrients like cyanide, tannins and phytates (Iyayi et al., 1997; Akpan and Ikenebomeh, 1995).

The use of biotechnological option by way of microbial inoculation of cassava wastes has presented a very viable and cost effective panacea to these constraints militating against the use of agro-industrial wastes like cassava peels (Olowofeso et al., 2003; Israelides et al., 1998; Oke, 1994). A trial was conducted by Oboh and Akindahunsi (2003) on the fermentation of cassava peels with a consortium of microorganisms in which the sun-dried fermented peels were analyzed for proximate, mineral, anti-nutrient composition and protein digestibility. The results of their trial are as presented in Tables 3, 4, 5 and 6.

These authors concluded that in view of the significant increase in protein content and digestibility of the microbially treated peels versus the untreated. control, such fermented cassava-by-product could be a good supplement in compounding animal feed.

Nwafor and Ejukonemu (2004) in Nigeria, experimented with three species of amylolytic fungi *(Saccharomyces cerevisiae, Mucor spp.* and *Rhizopus spp.*) in a solid substrate that contained 80 g of cassava waste powder, 125 g of $(NH_4)_2SO_4$, 1.25 g of urea and 1.0 g of KH_2PO_4. The results of their trial after 6 days of fermentation are presented in Table 7 below. They concluded that protein content of cassava wastes could be enhanced substantially using some microorganisms that are capable of utilizing the wastes as the sole carbon source and that moulds are better protein enhancers than yeasts because the hyphal growth of moulds was able to penetrate and spread through the substrate better than the yeast.

In another experiment with layers, Olowofeso and Omisami (2008) treated cassava peel with yeast culture at a graded level of 0-0.6% inclusion and concluded that sun-dried cassava peels treated with yeast culture resulted in better economic gains with no compromise on performance.

Cassava leaves

The high points in favour of cassava leaves as a potential feed resource for man and his livestock are its relatively high crude proteins, minerals and vitamins (Bokanga, 1994). According to Aletor and Fasuyi (1997), cassava leaves constitute a major by-product of cassava tuber harvest in all cassava producing countries in Africa. The proportion of leaves to the whole plant was reported by Tewe (1996) as constituting over 6%. The utilization of

Table 3. Proximate composition of fermented cassava peel (% dry weight).

Sample	Inoculated fermented	Naturally fermented	Unfermented
Ash	6.7^{a}±0.5	6.0^{a}±0.2	6.4^{a}±0.4
Moisture	5.1^{a}±0.4	5.7^{a}±0.2	5.1^{a}±0.3
Protein	14.0^{a}±0.2	11.1^{b}±0.3	8.2^{c}±0.1
Fat	3.3^{a}±0.1	3.5^{a}±0.2	3.1^{a}±0.4
Crude fibre	10.4^{b}±0.3	6.5^{c}±0.5	12.5^{a}±0.2
Carbohydrate	60.5^{b}±0.5	67.3^{a}±0.4	64.6^{a}±0.2

Values are means±S.E (n = 3). Means with the same superscript letter(s) along the same row are not significantly different (P>0.05). Source: Oboh and Akindahunsi (2003).

Table 4. Mineral composition of fermented cassava peel (%dry weight).

Sample	Inoculated fermented	Naturally fermented	Unfermented
Calcium	0.03^{a}±0.00	0.03^{a}±0.00	0.03^{a}±0.00
Sodium	0.04^{a}±0.00	0.04^{a}±0.00	0.04^{a}±0.00
Potassium	0.05^{a}±0.00	0.06^{a}±0.00	0.05^{a}±0.00
Zinc	0.01^{a}±0.00	0.01^{a}±0.00	0.01^{a}±0.00

Values are means±S.E. (n = 3). Means with the same superscript letter(s) along the same row are not significantly different (P>0.05). Source: Oboh and Akindahunsi (2003).

Table 5. Anti-nutrient composition of fermented cassava peel (dry weight).

Sample	Inoculated fermented	Naturally fermented	Unfermented
Cyanide (mg/kg)	15.2^{c}±0.1	23.3^{b}±0.2	44.6^{a}±0.2
Phytate (mg/100g)	874.4^{b}±0.1	705.1^{c}±0.2	1043.6^{a}±0.1

Values are means±S.E (n = 3). Means with the same superscript letter(s) along the same row are not significantly different (P>0.05). Source: Oboh and Akindahunsi (2003).

Table 6. *In-vitro* multi-enzyme protein digestibility of fermented cassava peel (%dry weight).

Sample	Protein digestibility
Inoculated fermented	75.1^{a}±2.1
Naturally fermented	67.5^{b}±0.7
Unfermented	66.0^{b}±3.1

Values are means±S.E (n = 3). Means with the same superscript

cassava leaves by livestock is also constrained by the high HCN content, low energy, bulkiness and possibly by their high tannin content (Ravidran et al., 1986). Bakrie (2002) in a review article wrote that cassava leaves are nutritionally valuable products and that cassava plant could yield 7-15 tonnes of leaves per hectare, which would account for an additional one tonne of valuable protein and 2.5 tonnes of carbohydrate per hectare.

The prospect of reducing these constraints to the barest minimum through microbial fermentation is very promising. For example, Darma et al. (1994) used *A. niger* to ferment cassava leaves and reported an increase in protein content and digestibility of dry matter and protein. In another trial with *A. niger*, Bakrie et al. (1995) reported an increase in the crude protein content of cassava leaves from 19.2 to 25.6%. Feeding trials with fermented cassava leaves supported the initial view that it could be used as a very cheap substitute in livestock diet to mitigate perennial scarcity and high cost of conventional feed ingredients. Bakrie et al. (1996a) fed fermented and unfermented cassava leaves to three groups of 27 Ongole cattle and concluded that fermented cassava leaves were better utilized by cattle and may be able to replace soybean pressed cake in the diet.

Cassava starch residues/fibre/pomace

Cassava starch residues (CSR) are the fibrous wastes left behind after the extraction of starch from mechanic-cally rasped cassava tubers in the cassava starch processing factories. Cassava starch residue, also referred to as pomace is constrained by its high water content, very low protein and high fibre level (Aro et al., 2008). The proximate compositions of CSR as given by

Table 7. pH, moisture and protein content of cassava wastes after the growth of *Saccharomyces cerevisiae, Mucor sp.* and *Rhizopus sp.* for 6 days at 30°C.

Organism	pH		Moisture% (w/w)		Protein% (w/w)	
	Initial	Final	Initial	Final	Initial	Final
S. cerevisiae	4.0	3.00	60	63	2.03	6.45
	+4.0	3.01	60	62	2.03	9.76
Mucor sp	4.0.	3.02	60	62	2.03	9.00
	+4.0	3.03	60	62	2.03	16.30
Rhizopus sp	4.0.	3.00	60	62.2	2.03	10.50
	+4.0	3.10	60	61	2.03	18.05

+ = Second dose of nitrogenous supplements added after 48 hours of incubation.
Results are means of triplicate experiments.Source: Nwafor and Ejukonemu (2004).

these authors are: dry matter (15.80%), crude protein (1.12%), crude fibre (19.25%), ether extract (2.37%), ash (2.84%), moisture (84.20%) and nitrogen free extractives (74.41%). Devendra (1977) had earlier concluded that this cassava by-product is of low feed value that could probably be included in ration for cattle as it contains about 24% crude fibre and 55-70% nitrogen free extractives (NFE).

Fermentation through microbial inoculation has again been canvassed as a possible and the most plausible way by which this bulky waste could be transformed into a better-utilized feed ingredient for livestock. Manilal et al. (1987) using a solid substrate fermentation process fermented samples of cassava starch residues (which they called starch factory wastes) with *A. niger* incubated at 30°C for 5 days with or without substrate enrichment. The protein content increased from the initial 1.65 to 7.7% on the fifth day. In a related trial, Balagopalan and Padmaja (1988) used a solid state fermentation technique for protein enrichment of cassava flour and CSR with the fungus-*Trichoderma pseudokonigii* Rifai using minimum enrichment of the substrate with 0.15% of $(NH_4)_2SO_4$. The highest increase in protein content from the level of 1.28% was observed where cassava flour was used as the sole ingredient i.e. 14.32% on the 18th day of fermentation, which decreased to 13.10% on the 24th day. Protein content observed where CSR was used as the sole ingredient was 5.09% on day 18 from the initial 1.26%, which slightly increased to 6.18% on day 24 of fermentation. The increase in protein content of CSR from1.55 to 18.50% after fermentation with *A. niger* was also reported by Kompiang et al. (1995) and Nur (1995).

Aro et al. (2008) conducted a trial in which CSR was fermented separately with four species of fungus and two species of lactic acid bacteria for 14 days using the SSF technique. The four species of fungus employed in this trial were *Aspergillus fumigatus, A. niger, Aspergillus flavus* and *Saccharomyces cerevisiae,* while the bacteria were *Lactobacillus delbrueckii* and *Lactobacillus coryneformis*. The results of proximate, anti-nutrient composition and mineral profile of the CSR as compared with an untreated control are as shown in Tables 8, 9 and 10.

The authors concluded that the trial revealed the potential benefits that could be derived from microbial fermentation through substantial nutrient enhancement and biodegradation of anti-nutritional components of CSR while at the same time proffering solution to the environmental problems that could ensue from the deposition of such wastes into the environment.

Animal trials conducted with fermented CSR by Padmaja and Balagopalan (1990), Kompiang et al. (1995) and Nur (1995) on broiler chickens clearly highlighted the nutritional values of CSR which according to these authors did not show any significant effect on performance at 10% inclusion level (Kompiang et al.,1995), could be included more than 12% but should be less than 16% (Nur, 1995) and the possibility of the commercial broiler farmers switching over to a CSR based feed from the conventional feed (Padmaja and Balagopalan, 1990).

CONCLUSION

Microbial fermentation has played a significant role in the nutritional enhancement of erstwhile worthless and often discarded agro-industrial by-products generated through the harvesting and processing of cassava roots. Myriads of laboratory analysis and animal trials have revealed the nutritive values of microbially fermented cassava products and by-products. Fermentation has also helped in mitigating against the level of anti-nutrients in these products while at the same time helping to beef up the relatively low calorie content of such by-products like cassava peels and CSR In Nigeria, the focus of research efforts is on how to further increase the energy content of these agro-industrial wastes through microbial fermentation so that they could totally replace the very expensive conventional ingredients like maize, guinea corn and millet in practical livestock ration formulations.

Table 8. Proximate composition of cassava starch residues with or without microbial fermentation.

Parameters	T1	T2	T3	T4	T5
Moisture content (%)	5.16±0.91^{a}	3.66±0.26^{c}	4.52±0.65^{b}	3.09±1.46^{d}	2.83±0.21^{d}
Crude protein (%)	1.12±0.04^{c}	7.00±0.03^{a}	5.83±0.58^{b}	7.00±0.02^{a}	6.71±0.29^{ab}
Crude fibre (%)	19.20±0.23^{a}	14.77±0.48^{bc}	13.74±0.49^{bc}	16.92±0.44^{b}	18.18±0.50^{ab}
Ash (%)	2.74±0.04^{b}	3.04±0.29^{b}	3.96±0.25^{a}	3.63±0.21^{ab}	3.39±0.03^{ab}
Ether extract (%)	2.03±0.06^{d}	3.97±0.09^{b}	4.11±0.03^{a}	3.21±0.03^{c}	3.85±0.09^{b}
NFE (%)	74.81	71.22	72.35	69.24	67.86
ADF (%)	40.89±0.40^{a}	30.74±1.04^{d}	29.45±0.17^{c}	38.99±0.74^{ab}	38.46±0.24^{ab}
NDF (%)	17.64±0.06^{b}	4.02±0.03^{c}	10.16±0.01^{c}	12.20±0.04^{c}	34.17±0.02^{a}
Hemicellulose (%)	23.25	26.72	19.29	26.79	4.29

T1, unfermented and un-inoculated CSR; T2, CSR fermented with *A. fumigates + L. delbrueckii* and *L. coryneformis*; T3, CSR fermented with *A. niger + L. delbrueckii* and *L. coryneformis*, T4, CSR fermented with *A. flavus + L. delbrueckii* and *L. coryneformis*, T5, CSR fermented with *S. cerevisiae + L. delbrueckii* and *L. coryneformis*.
^{a,b,c,d} = Means in the same row but with different superscripts are statistically different (P<0.05). Source: Aro et al. (2008).

Table 9. Anti-nutrient composition of cassava starch residues with or without microbial fermentation.

Parameters	T1	T2	T3	T4	T5
Cyanide (mg/kg)	17.88±0.08^{a}	9.84±0.08^{c}	10.48±0.27^{b}	10.91±0.16^{b}	9.40±0.13^{c}
Phytate (mg/kg)	9.89±0.48^{a}	7.41±0.48^{b}	9.21±0.08^{a}	2.75±0.28^{c}	8.84±0.10^{a}
Oxalate (mg/kg)	270.10±2.54	56.32±1.29^{e}	158.78±1.70^{c}	203.45±0.81^{b}	95.39±4.60^{d}
Tannin (%)	^{a} 0.09±0.00^{a}	0.05±0.00^{b}	0.04±0.00^{bc}	0.04±0.00^{bc}	0.05±0.00^{b}
Saponin (%)	0.04±0.00^{a}	0.02±0.00^{bc}	0.03±0.00^{ab}	0.02±0.00^{bc}	0.01±0.00^{c}
Total alkaloids (%)	5.44±0.04^{a}	0.12±0.05^{d}	0.64±0.02^{b}	0.29±0.01^{c}	0.03±0.01^{e}

T1, unfermented and un-inoculated CSR; T2, CSR fermented with *A. fumigates + L. delbrueckii* and *L. coryneformis*; T3, CSR fermented with *A. niger + L. delbrueckii* and *L. coryneformis*, T4, CSR fermented with *A. flavus + L. delbrueckii* and *L. coryneformis*, T5, CSR fermented with *S. cerevisiae + L. delbrueckii* and *L. coryneformis*.
^{a,b,c,d} = Means in the same row but with different superscripts are statistically different (P<0.05). Source: Aro et al. (2008).

Table 10. Mineral profile of the unfermented and fermented cassava starch residues.

Mineral	T1	T2	T3	T4	T5
Calcium (ppm)	403.45±2.90^{ab}	410.23±1.97^{a}	308.18±0.23^{c}	416.45±1.43^{a}	392.08±3.67^{b}
Potassium (ppm)	384.76±2.76^{a}	410.08±3.98^{a}	315.27±2.43^{c}	292.36±3.07^{d}	276.19±3.46^{d}
Magnesium (ppm)	449.21±8.18^{c}	488.28±5.63^{b}	425.33±3.30^{d}	438.85±2.86^{cd}	511.17±4.15^{a}
Iron (ppm)	41.29±0.37^{a}	36.80±0.76^{b}	35.30±1.94^{b}	38.00±0.79^{ab}	34.12±0.54^{b}
Manganese (ppm)	ND	ND	ND	ND	ND
Copper (ppm)	ND	ND	ND	ND	ND
Sodium (ppm)	418.12±2.63^{d}	502.60±3.0^{3a}	477.14±5.70^{b}	433.21±2.93^{c}	441.32±3.63^{c}
Selenium (ppm)	ND	ND	0.81±0.02^{b}	1.60±0.09^{a}	0.83±0.03^{b}
Phosphorus (ppm)	257.10±2.75^{b}	531.30±2.54^{a}	239.50±2.68^{d}	236.40±2.87^{d}	246.40±1.82^{c}

T1, unfermented and un-inoculated CSR; T2, CSR fermented with *A. fumigates + L. delbrueckii* and *L. coryneformis*; T3, CSR fermented with *A. niger + L. delbrueckii* and *L. coryneformis*, T4, CSR fermented with *A. flavus + L. delbrueckii* and *L. coryneformis*, T5, CSR fermented with *S. cerevisiae + L. delbrueckii* and *L. coryneformis*.
^{a,b,c,d} = Means in the same row but with different superscripts are statistically different (P<0.05).
ND, Not Detected.
Source: Aro et al. (2008).

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