Technical innovations for small-scale producers and households to process wet cassava peels into high quality animal feed ingredients and aflasafe™ substrate

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Nigeria, the world's largest producer of cassava, harvests 54 million metric tonnes (Mt) of cassava tubers annually. More than 95 per cent of its uses require peeling which generates up to 14 Mt of waste annually; mostly due to challenges related to drying. Sun drying is practically impossible during the wet season and it takes 2–3 days in the dry season to reduce the moisture content of fresh peels from about 60 per cent to 20 per cent or less – a marketable state. This is a report on a multi-centre and multi-disciplinary research work (in its early stages) to better utilize the waste. Ongoing work is showing great potential and has so far dramatically reduced cassava peels moisture content to 12–15 per cent within six sunshine hours using only equipment in current use by small-scale processors and households. The considerably shorter processing ensures high-quality products, low in aflatoxins contamination. Also, in a small sample experiment, when compared to sorghum grains currently being used for the production of aflasafe™ as control, the pellets supported the sporulation of Aspergillus flavus *up to 87.5 per cent of the control with better cost effectiveness. The research challenges remain in terms of circumventing drying technologies, creating and maintaining product quality standards, and facilitating and catalysing collective action among adopters. Nevertheless, the research carries huge potential to address feed scarcity, contribute to food security and food safety, clean up the environment, and improve the incomes and livelihoods of people currently engaged in processing cassava tuber into food – 85 per cent of them women.*

Keywords: feed scarcity, food safety, cleaned environment, improved incomes and livelihoods of women

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LIVESTOCK PRODUCTION ALREADY ACCOUNTS for more than 70 per cent of all agricultural land and production is expected to more than double in the next 40 years to meet the rapidly expanding demand for livestock products, especially in developing countries where incomes are rising. With a fixed land base, it is imperative that the feed industry significantly boosts its production capacity from alternative and sustainable feed sources. Can cassava waste contribute to feed the feed industry with alternative ingredients as well as contribute to food-feed safety? The production of cassava has increased steadily in Africa and in Nigeria for the last 30 years, growing at an average rate of 3 per cent per year. Because of its resilience to global climatic change, and because of its affordability and easy storage underground, predictions are indicating that this trend will continue until 2050 and may in fact increase faster. Total cassava production for the year 2013 in Africa is about 158 Mt/yr which accounts for 57 per cent of the global production and in Nigeria alone it is about 53 Mt/yr (FAOSTAT, 2015). By 2050 African and Nigerian production could reach 350 Mt/yr and 150 Mt/yr, respectively, based on the observed 3 per cent growth rate in the last three decades. From the annual production, it has been calculated that in Nigeria alone cassava waste amounted to approximately 14 Mt/yr (calculated at a 25 per cent average in dry matter content); that is, about 30 per cent of the annual production. Currently, this huge amount of waste is hardly being used.

Trends in feed/animal source food demand vs. population growth

The world population is exponentially increasing to reach 9.5 billion people by 2050. Africa will have the highest population increase in the world – up to 2.4 billion by 2050 – and among all African countries Nigeria will experience the highest increase reaching 450 million people by 2050 (FAOSTAT website). The average annual percentage growth of world GDP was 2 per cent in 2013, while, for the same year and at market prices based on constant local currency, it was 4 per cent for sub-Saharan African countries. More than 60 per cent of the African countries had an annual GDP growth rate above 4 per cent and 25 per cent of them were enjoying annual growth rates above 6 per cent (World Bank, n.d.). These comparatively high growth rates combined with an exponential increase in population will result in a high and increasing demand for food and particularly for protein-rich food such as milk, meat, and fish. In addition to this demand, the population landscape is quickly changing in Africa. Already six countries have more than 50 per cent of their population in cities: Ghana, Nigeria, Cameroon, Gabon, Congo, and Angola. If today about 70 per cent of the African population resides in rural areas, by 2050 most of the African countries will have more than 60 per cent of their population in cities. This will call for higher agricultural production per farmer and also a higher production of livestock and fish per capita.

The production of livestock and fish in Africa and in Nigeria has been very steady for the last 15 years. In Nigeria, the total livestock production increased by 60 per cent between 2001 and 2011 and predictions indicate a 250-per-cent increase by 2050. In 2011, about 10 Mt of animal feed were produced and consumed in Nigeria which could reach 25 Mt/yr by 2050. As oceans are depleted of fish, aquaculture is exploding all over the world and particularly in Africa. Between 2000 and 2022, aquaculture will increase 15-fold in Africa and more than 30-fold in Nigeria. More than 500,000 t of fish feed were produced in Nigeria in 2011, projected to reach 1.5 Mt by 2022. Animal and fish feed are mostly produced in the country and this industry is looking at using all sources of protein, fatty acids, and starch. In the special case of fish feed, the price of top quality fish feed based on fish waste is increasing so much (US$2,500/t in 2014) that only 80,000 t were imported that year by Nigeria (personal communication with Jonathan Ibe, Feed Mill Manager, Durante Fish Industry, Ibadan; Durante Fish Industries website). Local solutions have to be found to allow production of fish at an affordable price for consumers.

Potential to fill the gaps from cassava waste and associated research challenges

Several avenues being considered for utilizing the huge quantities of cassava waste include as animal and fish feed, using it for energetic substrate to produce aflasafe™, or growing mushrooms and other products for human and animal consumption. Near infrared spectroscopy (NIRS) analysis in ILRI-India of cassava peel pellets produced in ILRI-Nigeria under the project showed that it had nutritionally similar energy value as some grains being used in the feed industry (Table 1).

Regarding food and feed safety, health and livelihood of farmers are threatened by the problems posed by aflatoxin-producing members of the *Aspergillus* section *Flavi* group. Aflatoxins cause several health problems including liver carcinomas, growth stunting, and reduced immunity when they are ingested in levels above the tolerable limit (Liu and Wu, 2010). Due to these health risks, trade restrictions are in place that regulate the importation and trade of produce containing aflatoxins. Aflatoxin regulatory limits range from 4 ppb to 35 ppb in food crops for human consumption (FAO, 2003). The use of non-toxin-producing strains

Table 1 Comparative nutritional value of cassava peel pellets to some common grains

Sample	*DM*	*Ash*	*EE*	*CPDM*	*ME (MJ)/kg*
Cassava peel pellets	90.77	8.44	0.58	3.98	9.41
Sorghum grains	88.24	4.74	1.60	11.36	9.28
Maize grains	90.65	1.18	1.64	11.34	9.71
Pigeon pea grains	90.86	7.09	1.92	13.17	6.95
Soybean cake	91.19	3.58	7.80	53.46	10.88

Note: DM = dry matter, EE = ether extract, CPDM = crude protein dry matter, ME = metabolizable energy, MJ = megajoules to compete with toxin-producing strains in their niche has been employed as a biocontrol strategy that is an addendum to the aflatoxin management strategies. The biocontrol method is used successfully in the USA in formulations such as Afla-Guard (Dorner and Lamb, 2006) and AF36 (Erlich and Cotty, 2004). Other strategies include good farm management practices and the use of disease-resistant and stress-tolerant crop varieties (Hell et al., 2010). Biological technology similar to AF36 has been developed using indigenous strains for different sub-Saharan African environments. This has resulted in elite strains being identified that are used in Nigeria in the aflasafe™ formulation (Bandyopadhyay and Cotty, 2011).

Since conducting experimental trials with aflasafe™, reduction in aflatoxin production of up to 99 per cent has been reported with carry-over effects in storage conditions (Bandyopadhyay, 2010). Sub-Saharan Africa is a region prone to perennial risk of aflatoxins due to its location between 40°N and 40°S of the equator (Strosnider et al., 2006). Pre-harvest aflatoxin contamination of maize grain occurs through the silk channel (Beti et al., 1995). Aflasafe™ was targeted at pre-harvest control, with identified post-harvest gains. Aflasafe™ is currently formulated by coating the elite non-toxin producers on sterile sorghum grains in a large-scale manufacturing facility domiciled in the International Institute of Tropical Agriculture, Ibadan, Nigeria. The use of sorghum is successful. Nevertheless, the potential use of cassava peel offers promising benefits. Our research explores the value of converting cassava peel into pellets as a substrate for aflatoxin-biological control strains. The major impact of this replacement will be in terms of food/feed security as this would spare estimated quantities of 450 t of sorghum grains that are required for producing aflasafe™ for an effective aflatoxin control strategy for 2015 alone. This will further reduce the production cost of aflasafe™ currently at $1.875 per kg (Bandyopadhyay, personal communication). Enabling cost reduction is a smart investment and important because the majority of the global population, particularly in sub-Saharan Africa, rely on smallholder farming and smallholder farmers for food supply (Herrero et al., 2010). The use of aflasafe™ as an input in staple crop (e.g. maize, groundnuts) protection will help increase crop value and improve health conditions, particularly because of challenges of using predominantly rain-fed agriculture, which predisposes crops to drought stress, as opposed to irrigation farming. Converting a waste to a resourceful product will also be a waste management strategy and an income-generation opportunity.

The present paper reports progress being made to realize the potential to use cassava peels to produce animal feed for the livestock industry and using bespoke pellets from cassava peels to replace sorghum seeds in the aflasafe™ industry. Although cassava waste is relatively energetic, it is poor in proteins and other important ingredients such as minerals and vitamins. Formulations with additional nutrient complements will have to be found to produce competitive feed. Collecting cassava waste at an affordable cost and innovative drying methods for cassava peels will have to be worked out at minimal costs. All of these elements will have to be optimized to compete with existing animal feed formulas.

Materials and methods

The core approach of this research is essentially to apply the same traditional methods for processing cassava flesh into garri (cassava fufu) to processing cassava peels into new, high-quality products that are attractive to industry as alternative ingredients for livestock and fish feeds. The rationale for this approach was that same treatment for the flesh as for the peels would mean use of similar equipment and similar processes to which households and small-scale processors have been accustomed over the years. As such, should the research yield desired products, adoption by these groups that process up to 90 per cent of the cassava produced in the country would have a higher likelihood than otherwise would be the case. Processing cassava flesh in garri involves grating, dewatering, sieving, and drying by toasting on a fire-heated pan to reach the final product which normally has about 12 per cent moisture content. Processing cassava peels into dry mash and pellets departs from the garri making in that drying is by sunlight instead of toasting. However, this is likely to become inevitable in the rainy season when sunshine hours are fewer and therefore limit solar drying as the sole approach. For the rainy season, the use of coal or fuel wood to toast the mash would increase the cost of production. However, this is also the period of the year when the price of maize (the closest substitute for cassava peels mash for the feed industry) is highest. Though we are yet to operate and gather evidence for production during a rainy season, we hypothesize that the increased cost of production at that time would be compensated by the improved price of the product.

Meanwhile, both cassava peels mash and garri production benefit from particle size reduction, through grating, that facilitates moisture reduction. For cassava peels, moisture loss is designed to happen in two phases: 1) quick phase, where moisture loss is achieved through physical means using pressure generated by a hydraulic press; and 2) slow phase, where the increased surface area of grated material facilitates further moisture loss by sun drying, complemented by toasting as may be necessary especially during the rainy season. Steps in the process and the sequence of events are shown in Figure 1. A brief description of each event follows. Also see http://youtu.be/JwfgyHKnkLE for a video clip of the process.

Fresh peels selection

Fresh peels obtained from the cassava processing centres need to be sorted to remove stumps and any foreign objects which slow down the grating process besides increasing the wear and tear and causing occasional damage of the steel drum used for rasping. Peels should be grated on the same day as this ensures easy flow of grated material and products are less amenable to microbial contamination. Stored peels are usually sticky, slow down the grating process, and show physical signs (spots) of microbial growth on the inner (soft) surface of the peels as against the clean and uniform milky colour of fresh peels.

Grating

Grater design used for peels is slightly different from the regular grater used for grating cassava tubers for garri production (Figure 2).

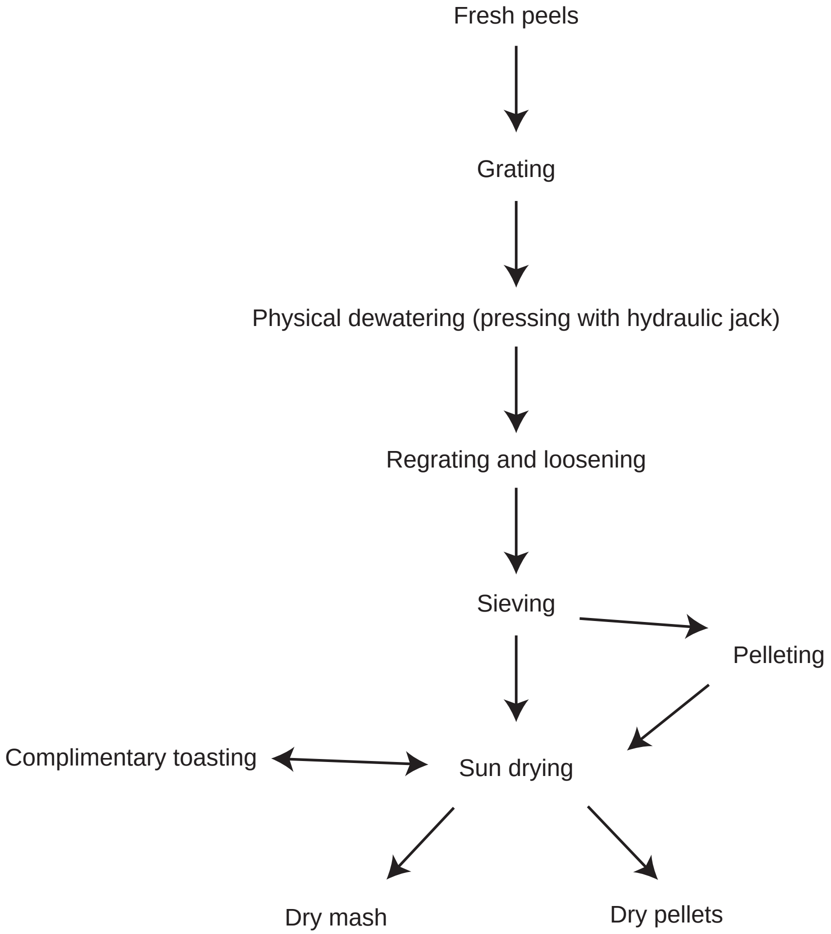

Figure 1 Steps in converting cassava peels into high quality mash and pellets

The grater uses a steel drum with grater corrugations/roughened sharp surfaces tightly arranged in a crisscross pattern across the surface of the drum to maximize grating. Fresh peels from the hopper pass through the narrow gap between a stationary piece of hard wood and a rotating drum for rasping. The gap between the wood and drum is kept narrow to ensure that fine peels do not escape grating. The grater also has a taller and more voluminous hopper to increase contact of peels with the rasper by gravity; this is sometimes further facilitated by manually pushing the peels with a piece of wood. Given the relatively harder nature of peels and the size, the mechanism of grating is not as efficient as when grating tubers where it takes one cycle of grating tubers to achieve the desired particle size. To achieve the desired particle size with the fresh peels the material has to be grated thrice. On average, it takes about 1.5 hours for a 7.5 HP grater to grate 300 kg of fresh peels thrice; that is, approximately 5 hours per tonne. Consideration is being given to pulverizing with a

Figure 2 Modified grater for cassava peels

hammer mill as a first step before passing material for grating. This would eliminate the need for sorting stumps and possibly increase grating efficiency (Thierry Tran, personal communication, CIRAD, France).

The moisture content of wet mash (post-grating) is expected to vary by season. Experiments (n = 17 batches) so far – conducted in the dry season – indicate an average of 60 per cent (ranging from 51 to 71 per cent, std. dev. 6).

Physical dewatering

Grated material is packed in smaller quantities of about 10 kg each in several woven plastic bags that allow easy drainage of fluid. Packed bags are arranged in multiple layers (one over the other) in a sturdy metal cage sandwiched between planks (top and bottom) with space at the top for a 30-tonne hydraulic jack (Figure 3). Physical dewatering is then achieved by jacking and extending the telescopic arm of the jack which in turn applies pressure on the bags leading to forceful expulsion of fluid. Squeezing continues until visible liquid loss from the draining channel ceases. The entire dewatering operation, packing grated material into bags, loading them into the press, and squeezing out liquid, lasts for 1 hour and 30 minutes to 2 hours. The moisture content of the dewatered mash (post-pressing) is not expected to vary by season because similar pressure only achieves a certain level of moisture content before oozing of liquid from the press ceases. Experiments (n = 210 samples) so far indicate an average moisture content of about 41.01 per cent (std. dev. 0.837) for dewatered mash (cassava peels cake).

Figure 3 Physical dewatering using a hydraulic press

Re-grating and loosening

The cassava peels cake resulting from the dewatering process needs loosening to facilitate sieving. This is achieved by grating the cake and this additionally improves earlier attained granularity.

Sieving

Sieving is aided by a motor-driven shaker fitted with a 3-mm sieve (Figure 4).

Mash from loosened cake is sieved to separate it into two fractions: 1) a fine fraction (lower in fibre and higher in energy content – more suited as ingredient for monogastric rations); and 2) a coarse fraction (comparatively higher in fibre but lower in energy content – suitable for ruminants). Proportions of fine and coarse fractions can be varied by varying the sieve sizes and this has implications for nutrient composition of the resulting fractions.

Drying experiments

Drying experiments are geared towards being able to advise adopters on their optimal processing capacities given drying space and drying surface available to them (see Figure 5 for layout). Five common surfaces are in use: 1) bare concrete slab; 2) plastic sheeting on concrete slab; 3) plastic sheeting on grass; 4) aluminium sheeting on grass; and 5) zinc-coated iron sheeting on grass. Re-grated material, usually about 40 per cent moisture, is spread during sunshine hours (from about

Figure 4 Sieving machine showing fine fraction (in bowl) and coarse fraction (trapped in the hopper)

10:30 a.m. to 4:30 p.m.) at the three thicknesses (4, 6, and 8 kg/m^2); weight loss is recorded every two hours and the final moisture content for each replicate calculated at the end of six hours based on total moisture loss (kg) and moisture content at start (per cent) as follows:

If
Moisture content per unit weight at start = x
and
Weight of mash at start = W_0
Weight of mash after h hours in the sun = W_h
then
Moisture loss after h hours = $x - (W_0 - W_h)$ and
Moisture content of mash after h hours = $x - (W_0 - W_h) \times 100 / W_h$

Weather data on temperature at the times of making observations, humidity and wind speed were collected from the Meteorological Unit of IITA to elucidate the results of the drying experiments (Table 2). These would be further utilized in subsequent reports to analyse their correlation with rate of loss of moisture by wet mash.

Pelleting

Experiments are ongoing to find optimal conditions for processing mash into pellets as may be demanded by end-users; in some cases to reduce the dustiness of the dry mash and in other cases to attempt to replicate the rheological characteristics of a grain (e.g. sorghum) for use in production of aflasafe™. Moisture content of mash being fed through the hopper of the pelleting machine is a big factor in strength, shape, smoothness of pellets, and quantity produced per unit time, etc. (Figure 6).

Figure 5 Drying experiments' layout

As such, pelleting at various moisture levels is still being tried. Also, moisture content and particle size of mash are important attributes that determine pellet storability. Whole grated mash or sieved fractions – fine and coarse fractions – can all be used to produce pellets.

Table 2 Weather data from IITA's Central Weather Station (opposite the factory)

Month	*Description of data*	*Observation time**				*Mean*
		10:30	*12:30*	*14:30*	*16:30*	
Jan	Average of Temp. (°C)	25.5	29.5	32.2	33.1	30.1
Feb	Average of Temp. (°C)	28.1	31.2	33.0	33.9	31.5
Mar	Average of Temp. (°C)	28.7	31.6	33.9	34.1	32.1
Jan	Average of W/Speed	6.9	6.0	4.9	3.7	5.4
Feb	Average of W/Speed (km/hr)	4.1	5.7	4.9	3.3	4.5
Mar	Average of W/Speed (km/hr)	3.6	4.6	4.9	4.7	4.5
Jan	Average of Hum. (%)	58.0	46.0	37.7	33.9	44.0
Feb	Average of Hum. (%)	81.4	64.4	55.2	50.5	62.9
Mar	Average of Hum. (%)	80.5	64.5	52.8	50.5	62.1
	Grand Average of Temp. (°C)	27.2	30.7	32.9	33.7	31.1
	Grand Average of W/Speed (km/hr)	5.1	5.5	4.9	3.9	4.8
	Grand Average of Hum. (%)	71.8	57.3	47.7	44.0	55.2

Note: *Corresponding to start up time (10:30), 1st weight measurement (12:30), 2nd weight measurement (14:30), and final weight measurement (16:30)
Source: Geospatial Laboratory, IITA, Ibadan

Figure 6 Pelleting machine with loose mash (in hopper) and pellets in the plastic receptacle

The above is ongoing work which is gradually leading to the development of protocols for the various products – especially for high quality mash for poultry and ruminants and high quality pellets for poultry, ruminants and aflasafe™ production. Further planned refinements in the materials and methods protocol include: rasper design, efficiency of physical dewatering through hydraulic press, sieve size for optimum yield of quality fine fraction, combinations of spreading thickness of wet mash and drying surface in different seasons for faster drying, and conditioning of the mash – optimum moisture and particle size for production of pellets for various end-uses.

Preliminary results and principal achievements

Results from the initial batches are presented here. Ongoing work is showing great potential and has so far consistently achieved dramatic reduction of cassava peels' moisture content within six hours of sun drying at temperatures ranging from 23 to 34°C, wind speeds of 3–7 km/h, and humidity levels of 34–81 per cent (Table 2). This has been without deploying any drying equipment but using equipment in current use by small-scale processors and households.

Physical dewatering

During the dry season months of January–March 2015, and based on 17 experimental batches, we found that fresh peels had an average moisture content of 60 per cent (range 51–71 per cent, std. dev. 6 per cent) after grating. The hydraulic press enabled an average water loss of 0.452 kg (range 0.407–0.508 kg, std. dev. 0.029 kg) per kg of grated cassava peels mash (Table 3).

Preliminary results of drying experiments conducted during January to March 2015 (dry season) indicate moisture loss per kg of mash over six hours to be highest

Table 3 Water loss per kg of grated cassava peels mash from physical dewatering

Description of data	*N*	*Mean*	*Minimum*	*Maximum*	*Std Deviation*
Weight of fresh cassava peels grated (kg)	17	286	132	372	60
Moisture content (%)	14	60	51	71	6
Weight of mash after physical dewatering (kg)	17	156	76	200	32
Water loss per kg (kg)	17	.452	.407	.508	.0293

Table 4 Effects of spreading thickness on rate of loss of moisture from wet cassava peel mash

	Starting quantity of wet mash (kg/sqm)	*N*	*Mean*	*Std. Deviation*	*Mean squares between groups*	*Mean squares within groups*	*F*	*Sig.*
Moisture loss per kg after six hours in the sun (kg)	4.00 (thin)	90	0.373	0.021	0.297	0.001	412.742	0.000
	6.00 (medium)	30	0.346	0.022				
	8.00 (thick)	90	0.260	0.033				
Moisture content of mash after six hours in the sun (%)	4.00 (thin)	90	5.472	2.452	5272.397	11.103	474.866	0.000
	6.00 (medium)	30	9.229	2.944				
	8.00 (thick)	90	20.513	4.121				

Note: Post hoc tests for multiple comparisons based on the LSD measure indicate that mean differences are significant at the 0.05 level.

in thinly spread (4 kg/m^2) replicates with a mean value of 0.373 kg compared to an average loss of 0.260 kg for the thickly spread (8 kg/m^2) replicates where moisture loss was lowest (Table 4).

Similarly, given the moisture content at the start of each drying experiment ranging from 39.80 to 42.52 per cent, sun drying achieved mean moisture contents of 5.47 per cent, 9.23 per cent, and 20.51 per cent respectively for the thin, medium, and thickly spread replicates (Table 4). All differences between replicates were statistically significant. As expected, the thinner the spread the higher the moisture loss and lower the final moisture content. In this case, the optimal thickness of spread to achieve a single digit moisture content within six hours of sunshine is <8 kg/m^2 and >6 kg/m^2. As explained above (see drying experiments), this study was undertaken to enable advocates to advise adopters accurately on their processing capacities given the drying spaces available for use by them. The practical implication for would-be adopters, for example, is that given the above range of spreading thickness, they can spread dewatered mash at 6 kg/m^2 in the dry season and expect to attain a single digit moisture content which feed millers demand. As such, a smallholder household with only 10 m^2 of drying space can spread out, in the morning, 60 kg of dewatered mash derived from about

120 kg of grated fresh cassava peels and get about 40 kg of dry, high-quality cassava peel mash in the evening of the same day during the dry season. This is work in progress and our data are currently limited to the dry season period. We are setting up the experimental designs for the rainy season which normally arrives in May in Nigeria.

Concerning drying surfaces, there was no significant difference between any of them in terms of influencing moisture loss (Table 5). This means that would-be adopters have a wide range of choices depending on availability and affordability. We are yet to determine the relative durability of the materials used as drying surfaces.

Results of analysing the effects of periods of the day and thickness of spread of wet mash on rate of moisture loss are summarized in Table 6. They show that moisture loss per kg of wet mash was lowest in the morning hours between 10:30 a.m. and 12:30 p.m. at which time they were similar for medium and thickly spread. Otherwise for the rest of the day, given dry season, the differences in rate of moisture loss were significant for both the period of the day and the thickness of spread. On the other hand, no differences in moisture loss resulted from the type of surface used for spreading and the period of the day (Table 7).

Table 5 Effects of spreading surface on rate of loss of moisture from wet cassava peel mash

	Type of drying surface	*N*	*Mean*	*Std. Deviation*	*Mean squares between groups*	*Mean squares within groups*	*F*	*Sig.*
Moisture loss per kg after six hours in the sun (kg)	Aluminium sheeting	42	.3253	.05583	0.002	0.004	0.449	0.773
	Zinc-coated iron sheeting	42	.3253	.05900				
	Plastic sheeting on grass	42	.3107	.06199				
	Concrete slab	42	.3239	.06125				
	Plastic sheeting on slab	42	.3195	.06119				
	Overall	210	.3209	.05958				
Moisture content of mash after six hours in the sun (%)	Aluminium sheeting	42	11.9784	7.47130	24.782	62.166	0.399	0.809
	Zinc-coated iron sheeting	42	11.9033	7.86295				
	Plastic sheeting on grass	42	13.7328	7.93108				
	Concrete slab	42	12.0433	8.13691				
	Plastic sheeting on slab	42	12.6174	8.00442				
	Overall	210	12.4550	7.83902				

Note: Post hoc tests for multiple comparisons based on the least significant difference (LSD) measure indicate that mean differences are insignificant at the 0.05 level.

Table 6 Effects of period of the day (morning, afternoon, early evening) and spreading thickness on rate of loss of moisture per kg of wet cassava peel mash

Time period	*Starting quantity of wet mash (kg/sqm)*	*N*	*Mean moisture loss (kg)*	*Std. Deviation*	*Mean squares between groups*	*Mean squares within groups*	*F*	*Sig.*
Between 10:30 am & 12:30 pm	4.00	90	.096	.046	.005	.001	4.411	.013
	6.00	30	.079	.015				
	8.00	90	.084	.021				
	Overall	210	.089	.034				
Between 12:30 pm & 2:30 pm	4.00	90	.142	.032	.057	.001	100.091	.000
	6.00	30	.115	.017				
	8.00	90	.092	.015				
	Overall	210	.117	.033				
Between 2:30 pm & 4:30 pm	4.00	90	.135	.044	.078	.002	49.198	.000
	6.00	30	.152	.011				
	8.00	90	.085	.041				
	Overall	210	.116	.048				
Between 10:30 am & 4:30 pm	4.00	90	.373	.021	.297	.001	412.742	.000
	6.00	30	.346	.022				
	8.00	90	.260	.033				
	Overall	210	.321	.060				

Note: Post hoc tests for multiple comparisons based on the LSD measure indicate that mean differences are significant at the 0.05 level for periods of the day between thickness of spread except in the morning hours when they are similar for 6 and 8 kg/m^2.

On the issue of high aflatoxin contamination of processed cassava peels dried over 3 days using traditional methods, it is important to report that the shortened drying time and processing of peels while fresh (same day) have contributed to improving product quality including ensuring that the levels of detectable aflatoxins in the products are well below the tolerable limit of 20 ppb for poultry feeds (Table 8).

Can cassava by-product and waste product contribute to feed resources?

Extensive work on use of cassava by-products and waste products was reviewed by Lukuyu et al. (2014) and proposals for new ways of treating and processing cassava peels into pellets have emerged from this report. Preliminary analysis of key feed quality traits of cassava pellets such as metabolizable energy content suggest that the pellets had 10.4 megajoule (MJ) metabolizable energy (ME) per kg dry pellets, which is close to the 11.95 to 12.79 MJ ME reported for tapioca feed stuffs – processed from whole cassava tubers – for ruminant and monogastric animals, respectively

Table 7 Effects of period of the day (morning, afternoon, early evening) and type of spreading surface on rate of loss of moisture from wet cassava peel mash

Time period	*Type of drying surface*	*N*	*Mean*	*Std. Deviation*	*Mean squares between groups*	*Mean squares within groups*	*F*	*Sig.*
Between 10:30 am & 12:30 pm	Aluminium sheeting	42	.0897	.03422	.001	.001	.582	.676
	Zinc-coated iron sheeting	42	.0929	.03285				
	Plastic sheeting on grass	42	.0821	.03407				
	Concrete slab	42	.0877	.03756				
	Plastic sheeting on slab	42	.0903	.03291				
	Overall	210	.0885	.03423				
Between 12:30 pm & 2:30 pm	Aluminium sheeting	42	.1195	.03631	.001	.001	.941	.441
	Zinc-coated iron sheeting	42	.1238	.03248				
	Plastic sheeting on grass	42	.1122	.02971				
	Concrete slab	42	.1154	.03832				
	Plastic sheeting on slab	42	.1123	.02829				
	Overall	210	.1167	.03322				
Between 2:30 pm & 4:30 pm	Aluminium sheeting	42	.1161	.04577	.001	.002	.349	.844
	Zinc-coated iron sheeting	42	.1086	.04424				
	Plastic sheeting on grass	42	.1164	.04870				
	Concrete slab	42	.1208	.05601				
	Plastic sheeting on slab	42	.1169	.04688				
	Overall	210	.1158	.04819				
Between 10:30 am & 4:30 pm	Aluminium sheeting	42	.3253	.05583	.002	.004	.449	.773
	Zinc-coated iron sheeting	42	.3253	.05900				
	Plastic sheeting on grass	42	.3107	.06199				
	Concrete slab	42	.3239	.06125				
	Plastic sheeting on slab	42	.3195	.06119				
	Overall	210	.3209	.05958				

Table 8 Summary of cassava peel product samples[1] analysed for aflatoxins B1, B2, G1, and G2 (ppb) at the Pathology Unit of the International Institute of Tropical Agriculture (IITA)

Sample ID	*B1*	*B2*	*G1*	*G2*
1	2.51	0.00	0.00	0.00
2	1.58	0.00	0.00	0.00
3	1.72	0.00	0.00	0.00
4	0.96	0.00	0.00	0.00
5	0.00[2]	0.00	0.00	0.00

Note: [1] Random samples from five different batches produced at a month's interval.
[2] zero means the aflatoxin level is below detection limit.

(Kirchgessner, 1997). The cassava pellet ME is also close to the ME contents of grains proposed as alternative feed such as sorghum. Interestingly the ash content of the cassava pellets was only 8.4 per cent showing that peel soil contamination will not be a serious issue in the pellet preparation.

As a further improvement in quality to reduce fibre content that reduces the nutritive value for monogastric animals, grated whole peel is sieved (approx. 2.5 mm sieve) to get fine (low fibre and high energy) and coarse (high fibre and lower energy) fractions in 2:1 proportions, respectively (Table 9). The fine fraction of peels with a low level of fibre will find favour with the feed industry preparing poultry feeds while the coarse fraction can be used in pigs and ruminants.

Two new products developed from cassava peels and industrial end-users demand for them

The considerably shorter processing time and use of freshly peeled/discarded materials is resulting in high-quality cassava peels products (pellets and mash) that are appealing to the livestock and fish feed milling industry as a versatile and new energy source, low in aflatoxins contamination. Independent estimates by one of

Table 9 Composition of grated peels, sieved fractions, and pellets based on wet chemistry

	% MC	*% Ash*	*% Nitrogen*	*% Protein*	*% Fat*	*Total CHO*	*% Sugar*	*% Starch*	*% CF*	*HCN mg/100g*
Grated peels	7.02	7.17	0.17	1.03	0.78	84.00	0.33	34.72	10.26	2.88
Fine fraction (2.5 mm sieve)	6.31	6.26	0.10	0.61	0.80	86.04	0.33	31.10	10.33	0.92
Coarse fraction	7.73	4.13	0.23	1.46	0.70	85.98	0.40	28.71	18.14	1.06
Fine pellets	11.35	5.38	0.21	1.30	0.82	81.15	0.69	43.70	11.72	2.15
Whole pellets	15.41	5.62	0.17	1.04	0.46	77.48	0.63	35.97	10.80	1.84

Note: MC= moisture content, CHO = carbohydrate, CF = crude f[2] hydrocyanide the top four feed millers in Nigeria based on the nutritional value of the mash and pellets put the willing-to-pay price of $110 equivalent to one-third the price of maize at the time of the estimation. However, NIRS analysis of the pellets in ILRI-India showed that it had nutritionally similar energy value as sorghum grain (Table 1). Further work and analysis should clarify the source of the discrepancy between industry and ILRI estimates.

In a small sample experiment conducted at the aflasafe™ demonstration scale plant in IITA, Ibadan, Nigeria, it was shown that when compared to sorghum grains currently being used for the production of aflasafe™ as control, the pellets supported the sporulation of *Aspergillus flavus* up to 87.5 per cent with better cost effectiveness. Given this sporulation rate and the landing cost of sorghum grains at the plant ($420/tonne), there is willingness to pay about $210/tonne of the pellets to replace sorghum for which the planned use for aflasafe™ production in 2015 alone is 450 tonnes.

Researchers in the project have shared samples of the products with interested private sector feed makers and commercial poultry farmers for chemical analysis and economic valuation. Joint poultry feeding trials at various inclusion rates in poultry rations are planned in 2015. The interested enterprises would provide 5,000 layers and 1,000 broilers with the project providing the cassava peels-based feed ingredients.

As we have started growing in confidence regarding the innovation, we invited four female and three male representatives of a garri processing centre to visit the ILRI cassava peel processing factory. Their garri processing centre has 68 processing units with a daily capacity of handling over 130 tonnes of cassava tubers throughout the year. The team was taken around the processing unit and the various operations involved in the processing of peels; grating, dewatering through the hydraulic press, sieving, and pelleting were demonstrated. They were excited and spontaneously went hands-on as they were already familiar with the equipment and processes, the main difference being the raw material and the end product. They expressed their willingness to take up the processing at their location with the group's own resources and requested technical assistance in processing and marketing the processed peels. Once the industry is assured of a regular supply of quality product through the cassava processors, linking the cassava producers with the feed industry would be a mutually beneficial relationship and ILRI will play a central role in catalysing this partnership. Further discussion on how this partnership would be forged will continue in the second quarter of 2015.

Research results will address some gender and equity issues in cassava processing

The cassava processing sector is mainly a small-scale, unorganized sector where women constitute about 85 per cent of the work force engaged in different operations of cassava processing. Any innovation in terms of value addition that results in labour reduction and revenue generation would be expected to benefit the women engaged in the cassava processing. In conducting research surveys, women-only groups were specifically formed and consulted separately. Large scale adoption of innovation could change the current dynamics; there would be price changes related to production costs and technical innovation and the enterprise would experience an influx of (new) entrants that could result in changes in the proportions of male and female peel processors. This would likely be in terms of labour input into operating the grating machines and in operating the hydraulic press for dewatering. Keeping women in control (majority) could involve empowering them to be owners of the processing equipment but this is only speculative at this time when industry demand for the products is still being promoted.

Challenges and future work

The use of cassava waste to produce animal and fish feed will face various difficulties including biological, energetic, nutritional, business, and policy issues. The use of cassava peels to feed animals has been known for a long period of time but it has never been effectively used to create a new market. This will require additional inputs in research and development. The feed industry is mostly based on corn and soybean, complemented by an array of additional elements such as cakes from groundnuts, oil-palm, blood, cereal by-products, fish waste, and more. Because cassava waste has very low proteins, fatty acids, and minerals, it cannot simply replace completely any of these primary ingredients, but can only partially replace them. In terms of business, this represents additional sources of ingredients meaning more effort, more energy, and ultimately more money. Even though demand for feed ingredients is very high, consulted feed millers and other potential end-users are more interested in getting ready-to-use ingredients than engaging in the production of cassava peel mash/pellets. This means that a new industry with a new set of entrepreneurs needs to emerge to cater to the demand by the multiple users conforming to their standards. Demonstrating the technical and economic feasibility of engaging in cassava mash/pellet production will be key in promoting the technology among would-be entrepreneurs to capture this market. Technologies to dry and pelletize efficiently and at low cost, associated with fortification with protein and minerals, could be demonstrated.

On the technical side, grating cassava peels including parts of the stumps which are tougher than the flesh results in quick blunting of the rasping drum. There is the need to work with the rasping and granulometry group to develop tougher raspers for cassava peels and determine optimum particle size required for optimum moisture reduction. Further economic drying of processed material in large quantities round the year is another major challenge that needs to be addressed. The research challenges especially to circumvent drying technologies and produce profitable products are subjects of further research. Equally challenging will be how to create and maintain standards in product quality as well as facilitate and catalyse collective action (for product collation for industries) among small-scale processors and households that take up the innovation. Lack of policy initiatives promoting the use of agro-by-products, financial assistance for small-scale processors, and institutions for strengthening capacity of stakeholders are other challenges that need to be addressed.

Protocols and appropriate machines for handling of cassava waste and production of value-added products will be developed and transferred to cassava processors to enable them to market their produce profitably. Potential consumers of the products – feed (poultry, aqua, ruminants) industry, aflasafe™, mushroom growers etc. – will be involved in the project from the initial stages of the product development to ensure that the end products conform to their requirements and effective market links are established. There is a proposal to further develop products of cassava waste to include high quality fish and poultry feed ingredients with up to 45 per cent protein and rich in fatty acids – up to 35 per cent content (including omega 3 fatty acids). This process ferments cassava waste using selected microorganisms and initial results are positive and indicate the possibility to reach 60 per cent conversion rate from waste to feed ingredient on a dry matter basis. The research team is aware that this type of product would more closely match feed millers' requirements and increase incomes to producers. However, that part of the research on utilizing cassava waste products is yet to receive research funding support.

This research on utilizing cassava waste products carries huge potential to address feed scarcity (millions of tonnes of livestock and fish feed), contribute to food security and food safety, clean up the environment, and improve the incomes and livelihoods of people currently engaged in processing cassava tuber into food – 85 per cent of them women. The co-localization of an exploding population, with an increasing demand for food, feed, and energy will call for increased agricultural production and productivity, which will in turn produce an increasing amount of waste. Nigeria, as the largest producer of cassava in the world and producing already up to 14 Mt/yr of waste, is well located for research and development efforts to transform cassava peels from a waste product and environmental nuisance into useful ingredients for animal feeds and many other potential uses.

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