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Cassava flour quality and the impact of cassava brown streak necrosis

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ABSTRACT

The main aim of this study was to investigate the quality and quantities of cassava flour produced and value chain development as a result of cassava brown streak disease (CBSD). Analysis of flour prepared from roots affected to various degrees of CBSD were assessed for various parameters such as starch and carbohydrate content, viscosity, pasting temperature, colour and pH. Values showed significant differences between the grades. There was a strong correlation (R^2=0.904) between flour viscosity breakdown and pH value, and with peak viscosity and pH value (R^2=0.737). A 25% level of CBSD root necrosis not only increased the conversion ratio of fresh roots to final product, but also presented an additional \$41-47/t for the cost of fresh cassava roots if necrotic tissue were removed, representing a significant economic loss.

Key words: Cassava; rural markets; small-scale; CBSD; pasting properties

BACKGROUND

Cassava brown streak disease (CBSD) has for many years been recognized as an important disease of cassava in coastal East Africa and the shores of Lake Malawi and Mozambique in the South, but more recently the disease is expanding towards central Africa in parts of Uganda, Kenya, Tanzania, Burundi, Rwanda and Congo.[1, 2, 3] CBSD

has become the most important biotic constraint to cassava production in eastern and central Africa in the last decade and the assumption has been that this negatively impacts value addition in terms of availability and affordability of fresh roots, as well as on the quality of processed cassava products such as the high quality cassava flour (HQCF). High quality cassava flour (HQCF) is being used successfully as a partial substitute for wheat flour in many African countries.[4] This is being helped particularly in parts of Uganda and Tanzania, by considerable technical assistance, capacity building of processing communities, and market promotion activities under initiatives such as the Cassava Adding Value for Africa (C:AVA) project (http://cava.nri.org/). The present study therefore seeks to establish (1) constraints arising from CBSD necrosis such as quality specifications, including the ability of farmers to meet market demand and the economic implications to processors. To our knowledge, no such report is currently available on these issues or on the functional properties of CBSD affected roots processed into flour.

HQCF differs greatly from the traditionally processed cassava flour, which typically are fermented (e.g. makopa, kondowole, lafun) to varying degrees[5], may contain extraneous material, and have high moisture contents, mould on the outer surface of dried roots. HQCF is a fine white powder produced from fresh cassava roots transformed from harvested root to packaged product within 24 hours.

Desired characteristics of HQCF include, bland taste, low cyanogen content (less than 10mg Kg^{-1}), fine particle size (less than 250µm), odourless, free from foreign matter and microbial contamination, with a moisture content of 10-12% and pH value between 5.5-7.5.[6, 7]

Under comparable agro-climate conditions, cassava is said to produce more carbohydrate weight per unit area than other staple crops.[8] On a small scale, cassava is

widely used in many tropical countries for feeding pigs, cattle, poultry, sheep, goats and fish.[9] The use of HQCF is being promoted across a range of uses from the bakery sector to the paperboard and plywood industries as a glue extender, thereby substituting the expensive wheat or corn starch. To achieve this, end users require a product that will produce free flowing glue with tight specifications for viscosity and pasting temperature. To ensure efficient adhesive bonding the HQCF must be low in fibre, free from contaminants, and be prepared from high quality cassava roots. The presence of fibre in flour used for adhesives will impair bond strength of the glue. Similarly, when used in baking and confectioneries, consistent and predictable flour properties are needed by bakers. Cassava varieties yielding high dry matter in the form of high starch but low levels of fibre [10, 11, 12] is desired, in order to maximise final product yield. Fermentation, where there has been an appreciable level of degradation of starch granules, will also impact negatively on the functional properties of flour flavour, colour and aroma when used as a substitute in the baking industry.

EXPERIMENTAL

Raw materials and field study

The study was conducted in Coast and Lake Zones of Tanzania, and Bukedi District in Uganda, respectively. With three villages per district and ten fields per village, assessments for CBSD were undertaken between 21st July and 8th August 2013. Within each field, fifteen plants, 8 – 10 months old showing above ground symptoms of CBSD, were uprooted in each of 10 fields in three villages per country. The harvested roots placed in sacks with a separate sack for each severity grade and the sacks were quickly delivered to the nearby processors. The cassava processed at each processing site consisted of a number of different varieties (up to five).   Varieties were not

differentiated during processing of each grade due to the difficulty of obtaining sufficient roots of each variety displaying each of the five root necrosis severity grades.

Fresh root grading

The grading score of Hillocks and Jennings was used.[1] Grade 1 roots were absent from brown streak necrosis. Grade 2 was assigned to minor traces of CBSD necrosis, whilst grades 3, 4 and 5 (deemed unfit for human consumption) represented around 25%, 35%, and > 50% presence of necrosis within the roots, respectively (Fig. 1). Roots were assessed visually when cutting the whole root longitudinally. Each grade was then processed into flour. All five grades were obtained for one processor in Uganda (batch 1) and two processors in Tanzania (batches 2 and 3), giving three replicates (n=15). The remaining batches were either consisting of grades 1 to 3 or 1 to 4 (n=22). There were a total of 11 processed flour samples from Uganda and 26 from Tanzania.
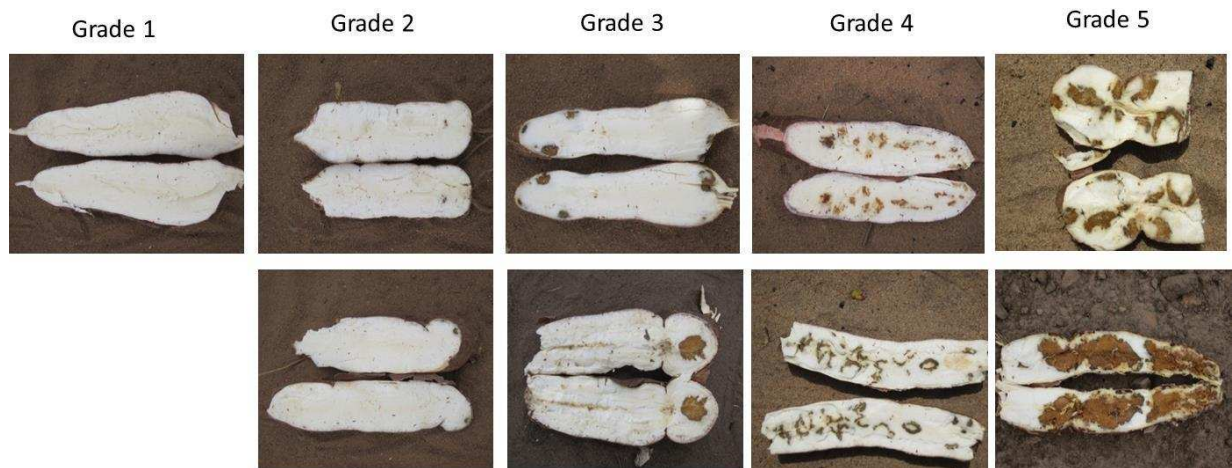

Figure 1: Grades 1 to 5 of unprocessed cassava roots-showing increasing presence of necrotic lesions

Processing HQCF

HQCF was prepared by processing groups (n=9) according to their standard commercial small-scale practices with one exception, i.e. that the necrotic tissue was not removed. Fresh roots were graded as described above, then peeled, washed and grated using a cassava grater (Tonnet Uganda Ltd or Intermech Tanzania Ltd). The resultant grated mash was loaded in 25 kg polypropylene sacks and dewatered using a 30 tonne hydraulic press for approximately one hour. The pressed material was broken down into a free flowing sample using the grater and spread on drying racks until the cassava grits were dry (~12% moisture content). For each grade of grits, a portion was then milled into flour for subsequent assaying. Processing of roots into dried product was completed within 24h, as is required for producing HQCF. Dried grits were used for pH and aroma evaluation, whilst milled flour samples were used for starch, carbohydrate and viscosity analyses (detailed below) and colour assessments.

Pasting properties

Pasting properties were determined using a rapid viscosity analyzer (RVA Model 3C; Newport Scientific Pty Ltd., Australia).[13] Pasting temperature, peak viscosity, final viscosity, setback and time to reach peak viscosity were compared across flour samples prepared from roots of three batches consisting of all grades (n=15). A sample of ~3 g of dried cassava flour was mixed with ~25 mL of water to form a slurry. Within the rapid visco analyzer (RVA), the sample was equilibrated at 50°C for 1 min, heated to 95°C, then cooled back to 50°C for 1 min over a 23 min cycle. The heating and cooling were at a constant rate of 11.25°C min^{-1}. The maximum viscosity (peak viscosity) was recorded as a curve by the RVA. Analyses were performed in duplicates.

Determining total starch and carbohydrate content

Determination of total starch content was made using a Megazyme kit according to manufacturer's instructions (K-TSTA 07/11) using the AOAC Official Method 996.11, based on thermostable α- amylase and amyloglucosidase.[14] Samples of 100 mg of milled (<0.5 mm) flour were weighed and transferred into 25 x 300 mm boiling tubes followed by the addition of 5 mL of aqueous ethanol (80% v/v), and incubated for 5 min at 80-85°C. The contents were mixed and a further 5 mL of aqueous ethanol (80% v/v) added. 2 mL of 2 M potassium hydroxide was added to each tube and the pellets re-suspended by stirring for 20 min in a water bath over a magnetic stirrer. Next, 8 mL of 1.2 M sodium acetate buffer (pH 3.8) was added while stirring, then 0.1 mL α-amylase and 0.1 mL amyloglucosidase (AMG), mixed and placed in a water bath at 50°C for 30 min with intermittent mixing with a vortex mixer. The solution was made up to 100 mL with distilled water and mixed. An aliquot was centrifuged for 10 min at 1,800 g. To duplicate aliquots (0.1 mL), 3 ml of glucose oxidase-peroxidase reagent was added (including D-glucose controls and reagent blanks) and incubated at 50°C for 20 min. The absorbance was recorded at 510 nm (n=37).

Determination of carbohydrates - Total carbohydrate was measured using the phenol-sulphuric acid method.[15] A sample of 100 mg of milled (<0.5 mm) flour was weighed and transferred into 25 x 300 mm boiling tubes followed by the addition of 5 mL of 2.5 N HCl. The samples were then hydrolysed by placing the tubes in a boiling water bath for 3 h prior to being cooled to room temperature. After cooling, the samples were neutralised with solid sodium carbonate until the complete cessation of effervescence. The sample volume was then made up to 100 mL prior to being centrifuged. After

centrifugation, 0.2 mL of the sample solution was transferred to test tubes and the volume was made up to 1 mL using distilled water. To each tube, 1 mL of phenol solution (5%) was then added followed by 5 mL of 96% sulphuric acid and the tubes were shaken constantly for 10 min. Finally, the tubes were placed in the water bath for another 20 min at 25-30 °C prior to reading at 490 nm. By this method, carbohydrates are hydrolysed to simple sugars by using diluted HCl. In hot acidic medium, glucose is dehydrated to hydroxymethyl furfural, which forms a green coloured product with phenol. The colour change is directly proportional to the amount of carbohydrates in the cassava flour. A glucose stock solution was prepared by dissolving 100 mg of glucose in 100 mL of water (1000 ppm). The stock solution was further diluted (1:10) to make a 100 ppm working standard required for the preparation of a calibration curve ($R^2= 0.9992$) at different concentrations. Accuracy of the method was verified using the certified reference material (BCR-380R, Sigma-Aldrich). Analyses were performed in triplicate (n=37).

Colour and aroma

Pictures were taken of the resultant processed dried cassava grits of the previously graded fresh roots. A Minolta colorimeter (Minolta Chroma Meter CR-410 was used to obtain L*, a* and b* values. L* = whiteness, a* = red-green, and b* = yellow to blue colours. L* = 100 indicates diffused white for batches consisting of all five processed grades (n=15).

Aroma was evaluated subjectively. Trained persons familiar with the characteristic aroma of processed cassava assessed all samples (n=37).

Acidity

The pH value across grades 1 to 5 was assessed using a standard laboratory pH meter. Five grams of cassava grits were mixed for 10 s in a glass beaker with 10 mL of distilled water using a glass stirring rod, and the pH reading taken within 60 s. Analyses were performed in duplicate (n=15).

Root yield losses by CBSD necrosis

(i) For each CBSD grade, 2 Kg of unpeeled cassava roots were used for the physical loss assessment studies in Uganda and Tanzania. Fresh cassava roots were peeled, and the necrotic portion removed and weighed as a total of edible root weight. The time taken for peeling each grade was also observed. The evaluation was performed in triplicate. (ii) The conversion ratio of fresh cassava roots to dried product was calculated and used as a determinant of the cost of processing quality grades 1 to 5. (iii) Feedback from the processor questionnaires (20) across both countries were also used to assess the impact from CBSD on production costs and marketing of end products.

Processor surveys

Three community processors in Uganda and six in Tanzania were interviewed to assess their perceived impact of CBSD on the value chain, and processed various grades of flour. A survey questionnaire was developed and used to elicit feedback from the processing group members. The questionnaire covered three areas, namely production, processing and marketing. All ten members of the group were encouraged to participate, consisting of both men and women. Where varying opinions were encountered, a consensus was eventually drawn. For quantifiable data (e.g. yields), where applicable, ranges have been given.

Statistical analysis

Data were subjected to ANOVA using Genstat for Windows 14th Edition. Least significant difference values (LSD; P = 0.05) were calculated for mean separation using critical values for t for two-tailed tests. Spearman's Rank Correlation was used to measure relationships between variables. Unless specified, all measurements were made in triplicate.

RESULTS AND DISCUSSION

Carbohydrate and starch analysis across different grades of processed cassava flour

Across cassava flour samples, only significant differences in the levels of carbohydrates (P<0.001; LSD=5.15) and starch (P<0.001; LSD=3.63) were observed between grades 5 and that of 1, 2, 3 and 4 (Figs. 2 and 3). The levels found here (with the exception of grade 5) are in line with findings from other research.
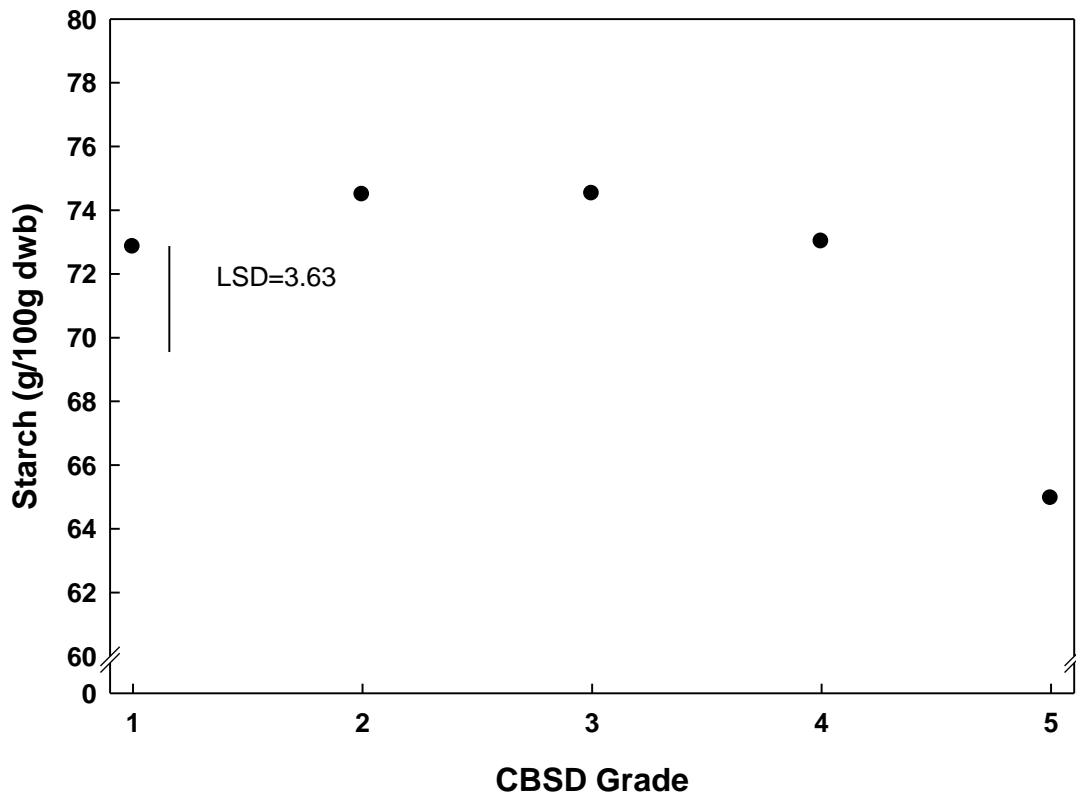
Figure 2: Starch content of cassava flour processed with different levels of root
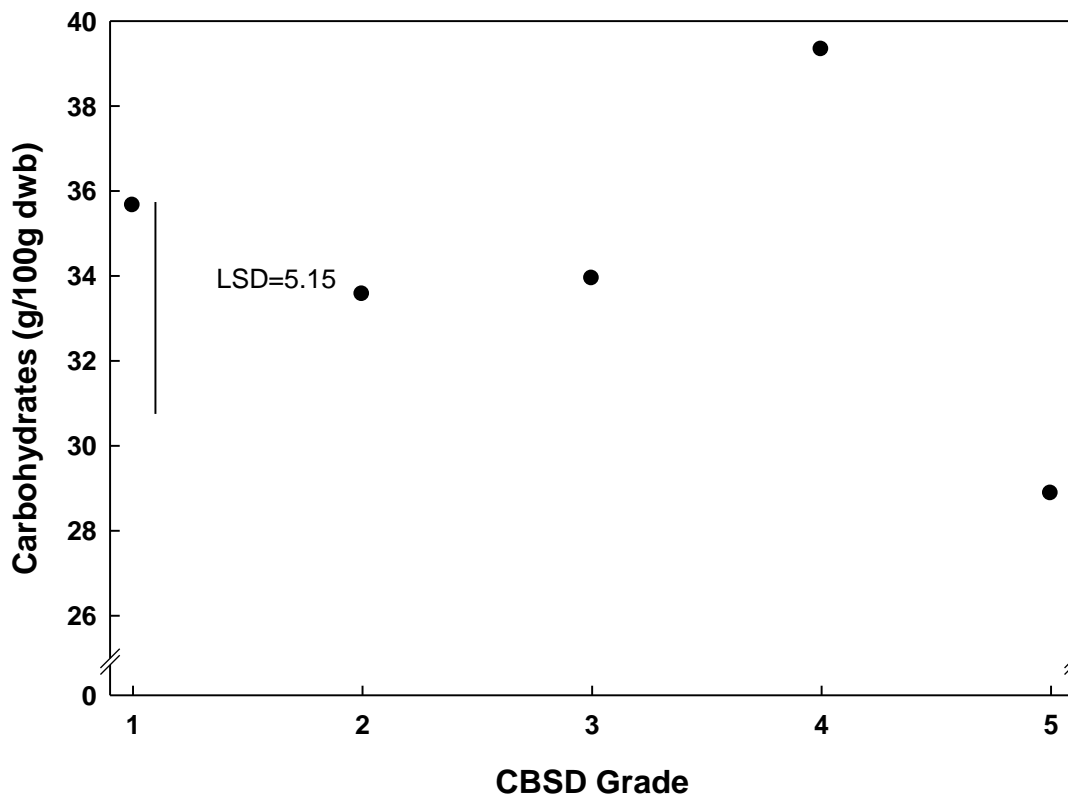
necrosis (n=37; P<0.001; LSD=3.63).

Figure 3: Carbohydrate content of cassava flour processed with different levels of root necrosis (n=37; P<0.001; LSD=5.15)

Viscosity and flour properties

Though the levels of starch within flours appeared not to differ across grades 1- 4 (Fig. 2), the quality of the flour did, as indicated by the peak, final viscosity values. Low viscosities are associated with molecular degradation of starch. This parameter is important because the properties of cassava starch dictate their industrial or food application. Final viscosity decreased with increased necrosis of roots used to make the flour (Table 1). Reduced peak viscosity in cassava flour is undesirable in the baking and paperboard or plywood industries for example, yielding an inferior end product. For grade 5 flour, it is assumed that lower starch content and quality was partly responsible for the lower viscosities.

Pasting temperature is strongly influenced by the cassava variety.[16, 17, 18] The pasting temperature gives the minimum temperature required to cook a given sample, and also indicates potential processing energy costs. Significantly, grade 5 flour could not be used as an adhesive in paperboard manufacture, for example, where a pasting temperature range of 63-66°C is desired[19], and grade 4 would yield an inferior bond strength compared to adhesive formulations utilizing grades 1 to 2, where final viscosities were much higher.

Table 1: Viscosity properties of flour prepared from roots of different grades of necrosis (grades 1 to 5; n=15)

Processed cassava grade	Peak viscosity (cP)	Final viscosity (cP)	Breakdown (cP)	Pasting temperature (°C)
Grade 1	2555	2609	1530	66.18
Grade 2	2445	2513	1396	66.56
Grade 3	2495	2487	1321	63.86
Grade 4	2434	2366	1233	64.70
Grade 5	1916	1853	755	70.24
P-value:	P<0.001	P<0.001	P<0.001	P<0.001
LSD:	55.7	61.3	88.5	3.74

Odour and pH

The greater the level of necrosis in the roots used to prepare the grits, the lower was the pH value of the resulting flour (Fig. 4), and the more pronounced was the off odour of the samples due to presence of necrotic rotting tissues. Work by Numfor[20] and others[21-22] established that lower pH values resulted in lower peak viscosities, which was also

apparent in the current study (Table 2). Nevertheless, the range found in this study was

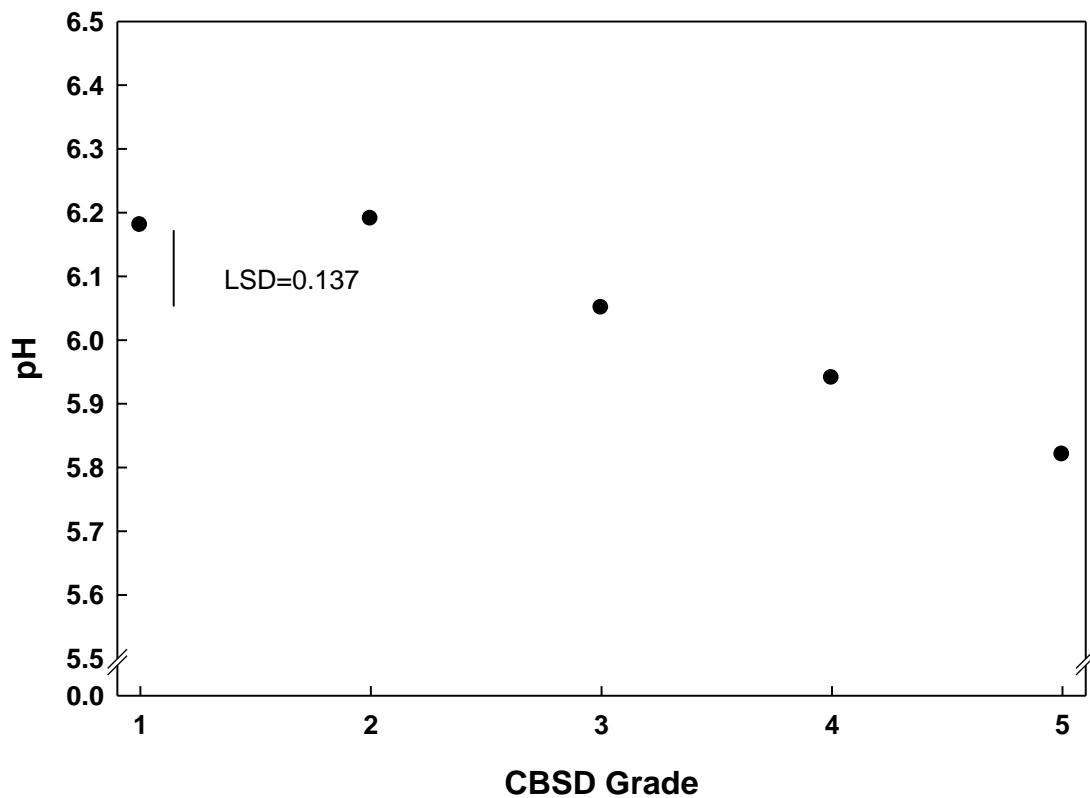acceptable for applications such as, as composite flour in baking and in breweries[23]

Figure 4: pH of value of cassava flour made from cassava roots affected by CBSD with

level of damage graded on a scale from 1 - 5 (n=15; P<0.001; LSD=0.137)

Colour and fibre

The colour differences between samples of grits prepared from roots with different

levels of necrosis were clearly observable (Fig. 5 and Table 2). These differences were

confirmed by objective measurements. L (whiteness) decreased as the CBSD grades

increased. Both a* (red-green) and b* (yellow to blue) values increased as flour quality

decreased. Such colour differences in end products made from cassava starch were

detectable.[24, 25] Again, for grade 3, where roots were removed, say, in order to improve

on the colour of the flour, this would present additional costs as highlighted previously (3.2). This difference in colour was observed consistently for flour samples made from either Ugandan or Tanzanian cassava varieties (results not shown).

| Grade 1 | Grade 2 | Grade 3 | Grade 4 | Grade 5 |

Figure 5: Colour of cassava grits prepared from cassava roots of different grades of necrosis

Table 2: Objective measurement of colour (L*, a*, b*) of grits prepared from cassava roots of different grades of root necrosis (n=15).

| Parameter | Grade | | | | | LSD | P-value |
	1	2	3	4	5		
L*	58.2	56.6	52.5	52.9	45.8	3.158	<0.001
a*	-0.32	-0.14	0.21	0.48	1.73	0.522	<0.001
b*	5.31	6.21	8.06	8.58	12.19	1.635	<0.001

Grits prepared from roots with grade 5 necrosis had very visible fibre present compared with other grades. According to Moorthy[26], the presence of fibre can delay gelatinisation. The time to reach peak viscosity did increase with poorer grades of flour (results not shown). For commercial applications, the lower the time taken to reach peak viscosity, the better.

Economic losses

There was no difference in the amount of peel (outer skin) removed from the roots across grades. This was expected. Peel represented ~15-20% of whole processed cassava roots. In terms of physical losses, there were significant (P<0.001) differences in resultant weight of fresh roots for processing following the removal of necrotic tissue (Fig. 3) across the various grades. Approximately 10% and 26% of the tissue was removed from grades 2 and 3 roots, respectively. In more severely affected roots, grades 4 and 5, 37% and 58% of tissue were removed respectively. When cassava was scarce, processors in Uganda reported accepting grade 3 and removing the affected part, whilst on other occasions, they would only remove necrosed tissue beyond grade 3. The damaged sections of the roots were used for livestock, or often simply thrown away into compost pits. A 25% level of CBSD root necrosis (i.e. grade 3) presented an additional $41-47/t for the cost of fresh cassava roots if necrotic tissue were removed (in relation to July 2013 market prices) during processing.

The conversion rate of fresh roots to final flour is variable, depending on cassava variety, age of roots, time of year. Low conversion rates, i.e. less input to greater output is desired by processors, generally, a ratio of between three and four to one. Without removing necrotic tissue, the conversion ratio of fresh roots to dried product across processed flour grades are presented in Table 3. There was a significant difference (P<0.001; LSD=0.266) in conversion ratios between grades 3 and 4.
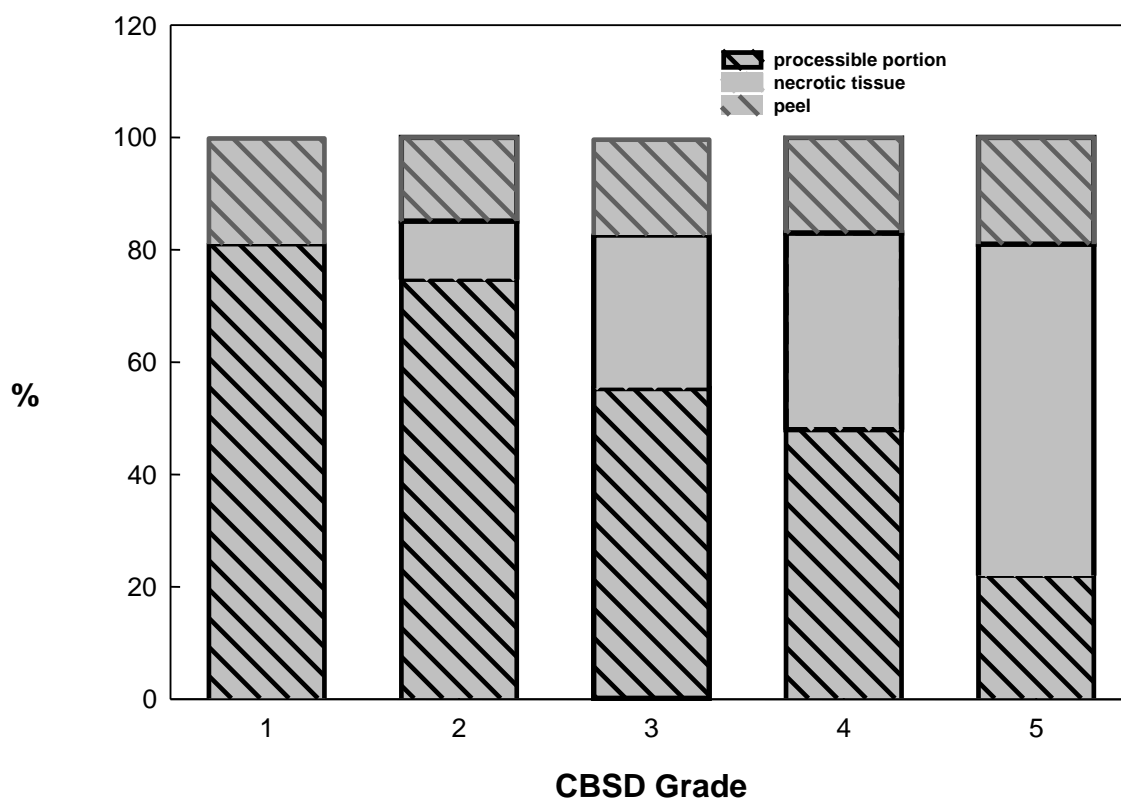
Figure 6: Proportion of losses during processing from clean and necrotic cassava roots of grades 2 to 5 when necrotic tissue is removed (n=9)

Table 3: Conversion ratio of fresh cassava roots to dried cassava grits for grades 1 to 5 of root necrosis and processing cost implications without the removal of necrotic tissue (n=37).

Cassava grade	1	2	3	4	5
Conversion ratio	3.5:1	3.5:1	3.6:1	3.9:1	4.3:1
Cost of roots ($/tonne)	175	175	175	175	175
Raw material cost per tonne of flour ($/tonne)	612.5	612.5	630	682.5	752.5
Difference in raw material cost ($)	-	0	18	70	140
% increase in cost for the processor	**-**	**0%**	**3%**	**11%**	**19%**

Source and quality of raw materials for processing

Processors generally source 50-80% of cassava roots from farmers own farms and produce traditional flour and/or HQCF. Across the cassava varieties grown within the processors farms in the study areas, there were few that processors were aware of as being free from CBSD. In Mtwara rural, processors indicated that the incidence of CBSD had been steadily declining in the recent years. In Uganda, 2/3 of processing communities thought that both the incidence and severity of CBSD was increasing. Cassava of quality grades 1 and 2 were most commonly available for processing. Disease severity surveys show that while the incidence of CBSD based on leaf symptoms was high at all locations, the severity of root necrosis was confined mainly to grade 2 and rarely exceeded grade 3 in the commonly grown varieties.[27]

For both countries, processor surveys highlighted the two most common reasons for growing the selected cassava varieties as being good processing characteristics and high yields (Fig. 7). Cassava varieties planted across the visited fields in Tanzania and Uganda typically matured at 8-12 months. Processors in Uganda in particular favoured early maturing (6-8 months) varieties, possibly to minimize the damage caused by the disease. CBSD necrosis was most prominent during the dry season with respondents citing Nov-Jan in Uganda and July-Sep in Tanzania as being the worst months for sourcing healthy roots for processing.

Currently, processors generally felt satisfied with the quality of roots they were using for producing cassava end products. Selected processors across Tanzania and Uganda estimated that they would lose ~10% cassava root weight due to grade 2 damage, and up to 25% for grade 3. This was a reasonably accurate estimation, also confirmed through the tissue loss study conducted during the field visits (2.9).
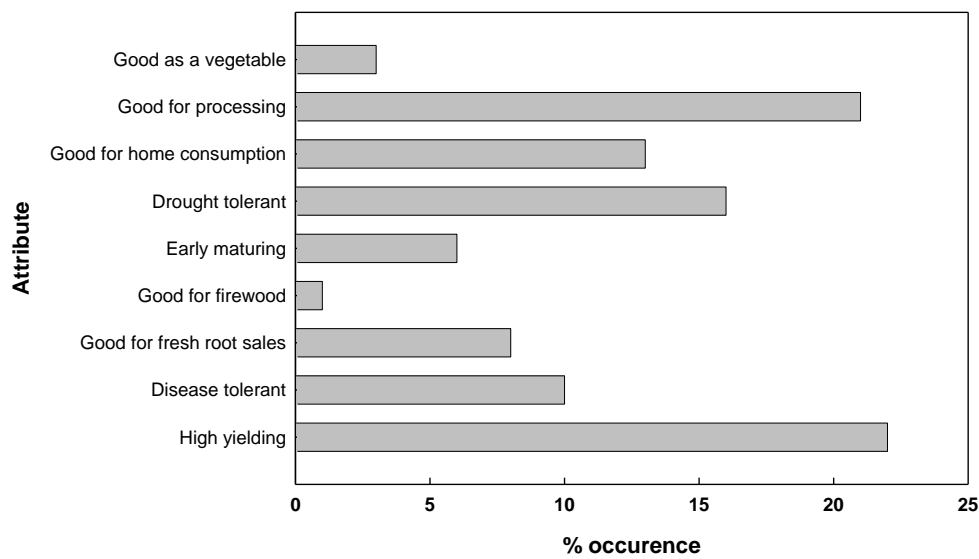
Figure 7: Cassava flour processors' (n=9) reasons for growing selected varieties across Uganda and Tanzania (2013)

CONCLUSION

This research has highlighted the importance of CBSD necrosis control because economic losses at grades 4 and 5 and the impact on quality are significant. Grades 1 - 3 flour should be reserved for applications where optimum functional properties are a requirement.

ACKNOWLEDGEMENTS

REFERENCES

1. Hillocks RJ and Jennings DL, Cassava brown streak disease: A review of present knowledge and research needs. Int J Pest Manage **49:** 225-234 (2003).

2. Legg JP, Jeremiah SC, Obiero HM, Maruthi MN, Ndyetabul AI, Okao-Okuja G, Bouwmeester H, Bigirimana S, Tata-Hangy W, Gashaka G, Mkamilo G, Alicai T and Kumar P, Comparing the regional epidemiology of the cassava mosaic and cassava brown streak virus pandemics in Africa. Virus Res **159:** 161-170 (2011).

3. Legg JP, Somado, EA, Barker I, Beach L, Ceballos H, Cuellar W, Elkhoury W, Gerling D, Helsen J, Hershey C, Jarvis A, Kulakow P, Kumar L, Lorenzen J, Lynam J, McMahon M, Maruthi G, Miano D, Mtunda K, Ntawuruhunga P, Okogbenin E, Pezo P, Terry E, Thiele G, Thresh M, Wadsworth J, Walsh S, Winter S, Tohme J, and Fauquet C, A global alliance declaring war on cassava viruses in Africa. Food Security **6:** 231–248 (2014).

4. Food and Agriculture Organization of the United Nations (FAO), Promising cassava flour can drastically cut costs for bakers (2013). [http://www.bakeryandsnacks.com/Ingredients/FAO-Promising-cassava-flour-can-drastically-cut-costs-for-bakers] Accessed 16 February 2015.

5. Mlingi NLV, Bainbridge ZA, Poulter NH, and Rosling H, Critical stages in cyanogen removal during cassava processing in southern Tanzania. Food Chem **53:** 29–33 (1995).

6. The African Organisation for Standardisation (2012). ftp://law.resource.org/pub/ars/ibr/ars.840.2012.pdf. CD ARS 840, First Edition. Accessed 26/04/2015.

7. Graffham A, Kleih U, Jagwe J, Nabawanuka J, Wanda K, Kalunda P, Ntibarikure G and Ferris S, A market opportunities survey for value-added utilization of cassava based products in Uganda. Part I: Demand analysis for industrial utilization, ASARECA/IITA monograph 3, IITA, Ibadan, Nigeria (2003).

8. Emmanuel OA, Clement A, Agnes SB, Chiwona-Karltun L and Drinah BN, Chemical composition and cyanogenic potential of traditional and high yielding CMD resistant cassava (Manihot esculenta Crantz) varieties. Int Food Res J **19:** 175-181 (2012).

9. Tewe OO, Cassava for Livestock Feed in sub-Saharan Africa. FAO and IFAD Publication (2004).

10. Apea-Bah FB, Oduro I, Ellis WO and Safo-Kantanka O, Principle component analysis and age at harvest effect on quality of gari from four elite cassava varieties in Ghana. Asian J Agric Res **8:** 1943-1949 (2009).

11. Apea-Bah FB, Oduro I, Ellis WO and Safo-Kantanka O, Factor analysis and age at harvest effect on the quality of flour from four cassava varieties. World J Dairy Food Sci **6:** 43-54 (2011).

12. Ademiluyi FT and Mepba HD, Yield and properties of ethanol biofuel produced from different whole cassava flours. International Scholarly Research Notices DOI: 10.5402/2013/916481 (2013).

13. American Association for Clinical Chemistry (AACC), 2005.

14. McCleary BV, Gibson TS, and Mugford DC, Measurement of total starch in cereal products by amyloglucosidase- α- amylase method: Collaborative study. Journal of AOAC International **80:** 571-579 (1997).

15. DuBois M, Gilles K, Hamilton J, Rebers P, and Smith F, Colorimetric method for the determination of sugars and related substances. Anal Chem **28:** 350-356 (1956).

16. Nuwamanya E, Baguma Y, Emammbux N, Taylor J and Patrick R, Physicochemical and functional characteristics of cassava starch in Ugandan varieties and their progenies. J Plant Breed Crop Sci **2:** 1-11 (2010).

17. Oladunmoye OO, Aworth OC, Maziya-Dixon B, Erukainure O, Elemo GN, Chemical and functional properties of cassava starch durum wheat semolina flour, and their blends. Food Sci Nutr **2:** 132-138 (2013).

18. Sriroth K, Santisropasri V, Petchalanuwat C, Kurotjanawong K, Piyachomkwan K and Oates CG, Cassava starch granule structure-function properties: influence of time and conditions at harvest on four cultivars of cassava starch. Carbohydr Polym **38:** 161-170 (1999).

19. Global cassava market study-Business opportunities for the use of cassava. Proceedings of the validation forum on the global cassava development strategy, International Fund for Agricultural Development (IFAD), Food and Agriculture Organization of the United Nations, Rome, Volume 6 (2004).

20. Numfor FA, Walter WM and Schwartz SJ, Physicochemical changes in cassava starch and flour associated with fermentation: effect on textural properties. Starch **47:** 86-91 (1995).

21. Adegunwa MO, Sanni LO and Maziya-Dixon B, Effects of fermentation length and varieties on the pasting properties of sour cassava starch. Afr J Biotechnol **10:** 8428-8433 (2011).

22. Julianti E, Lubis Z, Ridwansyah , Yusraini E and Suhaidi I, Physicochemical and functional properties of fermented starch from four cassava varieties. Asian J Agric Res **5:** 292-299 (2011).

23. Aryee FNA, Oduro I, Ellis WO and Afuakwa JJ, The physicochemical properties of flour samples from the roots of 31 varieties of cassava. Food Control **17:** 916–922 (2006).

24. Charles AL, Huang TC, Lai PY, Chen CC, Lee PP and Chang YH, Study of wheat flour–cassava starch composite mix and the function of cassava mucilage in Chinese noodles. Food Hydrocolloids **21:** 368–378 (2007).

25. Wang Y, Zhang M and Mujumdar AS, Influence of green banana flour substitution for cassava starch on the nutrition, color, texture and sensory quality in two types of snacks. LWT--Food Sci Technol **47:** 175–182 (2012).

26. Moorthy SN, Blanshard JWV, and Richard JE, Starch properties in relation to cooking qualities of cassava. In: Proceeding of the first international scientific meeting of cassava biotechnology network, ed. by Roca WM, Thro AM Working document No. 123. Centro Nationale De Agriculture Tropicale (CIAT), Cali, Colombia pp265-269 (1992).

27. Hillocks RJ, Maruthi MN, Kulembeka H, Jeremiah S, Alacho F, Ogendo J, Arama P, Mulwa R, Mkamillo G, Kimata B, Mwakanyamale D, and Benesi I, Disparity between leaf and root symptoms and the economic losses caused by cassava brown streak disease in four countries in eastern Africa. J Phytopathol DOI: 10.1111/jph.12430 (2015).