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Effective utilisation of cassava bio-wastes through integrated process design: A sustainable approach to indirect waste management

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ABSTRACT

An integrated process design, which can be applied in small-to-medium batch processing, was proposed. The process is based on the exploitation of intact (whole) cassava root, through optimisation of simultaneous release recovery cyanogenesis downstream processing for sustainable wastes minimisation and packaging material development.

An integrative seven unit process model flow was considered in the process design modelling. Using the release process models, it was possible to predict the maximum yield (45.8%) and the minimum total cyanogens (0.6 ppm) and colour difference (4.0) needed to avoid wastes and unsafe biopolymer derivatives. The process design allowed saving on the energy and water due to its ability to reuse wastewaters in the reactions and release processes. Drying rates, Scanning electron micrograph, Differential scanning calorimetry, Water vapour transmission rate and Fourier transmission infrared spectroscopy analyses have demonstrated the practical advantage of laminar flow hood air systems over oven-drying heat for integrated process design.

Thus, the integrated process design could be used as a green tool in production of cassava products with near zero environmental waste disposal.

1. Introduction

The continued demand for waste-free environments coupled with the unregulated and high costs of proper waste management, requires customised, robust, and inexpensive solutions to ensure sustainable waste minimisation. Currently, cassava by-products are increasingly contributing to the global hazardous wastes, industrial disasters and environmental health risks (Adeola, 2011; Kolawole, 2014). The poisonous nature inherent in most bitter cassava cultivars (Tumwesigye et al., 2016) contributes to some extent to environmental health risks, and this has been exacerbated by the decline of suitable disposal sites. The composition of cassava biopolymer derivatives is shown in Table 1. Previous research focus has been on minimising the environmental cassava wastes by developing them into valuable products (Ezejiofor et al., 2014; Raabe et al., 2015; Tumwesigye et al., 2016; Versino et al., 2015). However, with increasing population and small-to-medium processing (SMP) facilities of cassava, into starch and other products, for food, feed, and non-food applications, waste streams such as waste solids (WS) and wastewaters (WW) will be serious hazards. Cassava waste solids consist of the peel, internal root centre fibre (xylem bundles) and unwanted discard solids. Additionally, the above interventions are unilateral processes

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Table 1 – Composition of major cassava biopolymer derivatives.

Derivative	Total waste (%, w/w)[a]	Peel waste (%, w/w)[b]
Dry matter	30.13	
Ash	7.00	4.5
Crude protein	3.50	
Crude fibre	10.00	
Ether extract	12.00	
Neutral detergent fibre	52.00	
Acid detergent fibre	25.00	
Acid detergent lignin	11.00	
Cellulose	14.00	37.90
Hemicellulose	27.00	23.90
Holocellulose		66.00
Lignin		7.50
Hot water solubility		7.60
1% NaOH solubility		37.50
Moisture content		14.00

[a] Adeola (2011).
[b] Aripin (2013).

that are not integrated leading to increased waste costs. The WS and WW are usually characterised by acidification due to the hydrolysis of total cyanogens producing hydrogen cyanide which is toxic to household animals, fisheries and other organisms (Kolawole, 2014). Furthermore, serious environmental pollution such as foul odour and pathogen-suspended solid carriers are other components of WS and WW leading to surface and underground water and soil contaminants (Ubalua, 2007). Moreover, the greater numbers of SMP units, their poor and more time-consuming processing methodologies, and limited disposal routes, override WS and WW management capacities.

The inherent traditional processing nature of SMPs does not support process integration for the minimisation of waste solids (WS) and wastewaters (WW). Some approaches have been employed to minimise environmental accumulation of cassava WS and WW. Examples of the strategies used currently include cultivar selection for minimisation of residue generation and water consumption in the industrial processes (Maieves et al., 2011), bagasse for bioprocessing of organic acids, ethanol, aroma (John, 2009) and root peel production of biocomposites (Versino et al., 2015). Unfortunately, the underlying high processing costs, energy and time of the above and other strategies complicates further WS and WW minimisation. These strategies do not incorporate holistic approaches to process design, adding further constraints to sustainable WS and WW minimisation management. A sustainable cassava WS and WW minimisation solution can be approached by optimal design models of individual processes, as drivers that give best interface leverages. Examples of such leverages could be achieved by applying cassava wastes in packaging materials production using an integrated process design.

The integrated methodologies which emphasise process optimisations and consider production component synergisms and mathematical models are highly regarded as sustainable solutions for waste minimisation. The process design methods previously employed had been reported as graphical-based techniques such as water pinch' analysis and mathematical optimisation (Majozi and Gouws, 2009). While these techniques offer a striking approach for waste minimisation in large scale processing systems, there is need to develop simple attractive substitute process design that address environmental WS and WW of dominant cassava SMPs from a sustainable technological point of view.

The key aim of the study was to develop and optimise an integrated process design (IPD) for effective use of cassava wastes, and development of sustainable packaging materials. Specifically, the study investigated an optimal structure of simultaneous release recovery cyanogenesis (SRRC) using individual processes and process models. The purpose was to gain insight into important individual processes and models that would facilitate SRRC integration in order to maximise WS and WW utilisation while minimising water solvent usage. It was anticipated that such models would exploit individual process interfaces, bringing in synergies and lead to sustainable processes.

The study comprised process integration applicable to small-to-medium-scale batch processing of bitter cassava that contributes in part to accumulated environmental wastes. A case study for the development of packaging films demonstrating IPD improvement and application potential was undertaken.

2. Experimental

2.1. *Model development and optimisation studies*

2.1.1. *Waste derivatives yield*

The objective was to develop an all-embracing optimised waste yield model and provide a foundation from which other process models could be optimised, and support integration into holistic design. Waste derivatives were processed using the root biomass of intact bitter cassava following the method described by Tumwesigye et al. (2016) without modifications. The term, "waste derivatives" refers to the product recoveries from waste solids and waste water. Cassava biopolymer derivatives, comprises the major polymers (primary metabolites) of importance for the development of biobased materials, and include holocelluloses, lignin and starch. Processing intact root using SRRC produces fibre-rich derivative powder which has been found to deliver better mechanical and barrier properties (Tumwesigye et al., 2016).

The yield model was developed using a Box–Behnken-design by varying parameters namely buffer (0, 2, 4%, w/v), cassava waste solids (15, 23, 30%, w/w), and extraction time (4, 7, 10 min) based on experimental design (Table 2a). Data analysis was performed as described in Tumwesigye et al. (2016) using Statistica 7.1 software (StatSoft Inc., Tulsa, USA) The resulting process model was optimised with multi-response desirability model (Eq. (1)) (Derringer, 1980).

$$D = [d_y(Y)]^{1/n} \quad (1)$$

where D, over all desirability; Y, yield (%); $d_y(Y)$, yield desirability function; n, responses ($n = 1$); $d_y(Y) = 0$, perfectly undesirable; $d_y(Y) = 1$, perfectly desirable.

2.1.2. *Total cyanogens and colour*

Total cyanogens (TC) was analysed using the kit developed by Bradbury et al. (1999), and colour estimated by the colour difference (ΔE) using CR-400 Chroma Metre, Konica Minolta Sensing Japan. The TC and ΔE models were developed using a Box–Behnken-design with buffer (0, 2, 4%, w/v), cassava waste solids (15, 23, 30%, w/w), and sodium bisulphite (1, 2, 3%) based on experimental design (Table 2b). Their process