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Review

Integrated sustainable process design framework for cassava biobased packaging materials: Critical review of current challenges, emerging trends and prospects

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ABSTRACT

Background: Cassava represents a reasonable share in biobased material development globally. The production of its biopolymer derivatives using conventional techniques/methods is accompanied by significant wastes with potential negative environmental impact. Among the biopolymer derivatives, starch dominates as lone additive in cast matrices with packaging limitations, requiring other biopolymer derivatives, and/or external-source modifiers for matrix improvement. Exploiting integrated sustainable engineering process design of all biopolymer derivatives, is a novel approach in designing efficient system of cassava biobased materials for food and non-food applications.
Scope and approach: A critical review on the current and emerging techniques and methodologies to address cassava wastes and challenges of cassava research for application on biobased packaging are provided. The potential of integrated sustainable engineering process design framework for packaging system is discussed, and prospects for improvement suggested.
Key findings and conclusions: Challenges of significant waste generated during conventional processing and on the application process aiming at tailoring materials to industrial needs are reported. These materials should be improved using a holistic approach reflecting the target products, variable environment, minimising production costs and energy. Use of novel material resources, eliminating waste, and employing a standardised methodology via desirability optimisation, present a promising process integration tool for development of sustainable cassava biobased systems.

1. Introduction

The substantial global dependence on petrochemical based materials has given rise to packaging security concerns. These concerns, together with negative environmental impacts (Emmambux et al., 2004), increased population pressure on finite and dwindling natural resources and competition for food supply, have drawn the extensive research and development of sustainable alternatives. The sustainable alternatives that are green, clean, post-use biodegradable, compostable, efficient and sustainable are desired (Coombs & Hall, 2000). The based materials, which have emerged as main alternatives to address the concerns, are obtained from renewable resources which is a component of a sustainable biobased industry. Cassava (*Manihot esculenta* Crantz) represents a sustainable resource of biobased products (Hood, Teoh, Devaiah, & Requesens, 2013).

Thus, this critical review reports: (i) the current technologies and methodologies used to address cassava wastes, to apply cassava biobased materials in food industry; (ii) challenges with biobased material development using conventional processes; (iii) potential of integrated green engineering process design framework for sustainable packaging system development; and (iv) prospects for further improvement of the integrated process design.

2. Cassava as a versatile crop resource of biomaterials

Cassava is categorised into sweet or bitter, with sweet cassava being edible and safe for immediate use in fresh and processed forms, while the bitter ones are unsafe for immediate consumption.

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Cassava is consumed widely and highly valued as food security anchorage for tropical and sub-tropical countries. Mainly in Africa whereby more than half of the world's cassava or about 162.5 million t from over 15 million hectares, compared to more than 33 t (3.0 ha) and 92 t (5.0 ha) millions in Latin America and Asia, are cultivated (FAOSTAT, 2015).

Advancements in the biopolymer research triggered, in the last decade, the paradigm shift towards a fully industrial-applied sweet cassava (Adetunji, Isadare, Akinluwade, & Adewoye, 2015). Increasing awareness of the association between cassava biopolymer derivatives and cheap industrial biobased products might account for this trend. This popularity is due to its easily processed low cost biopolymer derivatives (Starch, cellulosic fibres, lignin, and hemicellulose) (Table 1). Of the biopolymer derivatives, starch has been extensively studied, perhaps due to its high root proportionality, chemical and functionality (Blazek & Copeland, 2009), and received a higher attention for biobased materials production (Paunonen, 2013). Starch molecular structures, with differentiated amylose (20–30%) and amylopectin (70–80%) contents (Mufumbo et al., 2011), presents unique polymer functionality in wide range applications. The proportionality of amylose and amylopectin in extracted and applied starch can differ significantly depending on production methodology and amounts used to prepare products. Amylose is a nearly linear polymer of α-1, 4 anhydroglucose units that has excellent film-forming ability, rendering strong, isotropic, odourless, tasteless, and colourless film (Campos, Gerschenson, & Flores, 2011). Amylopectin is a highly branched polymer of short α-1, 4 chains linked by α-1, 6 glucosidic branching points occurring every 25–30 glucose units (Liu, 2005). Consequently, amylose and amylopectin provide materials of varying viscosities, crystalline quality and the energy required to melt the material (Mufumbo et al., 2011).

3. Cassava starch production and environmental impact

Due to sweet cassava starch ease of processing, low cost and potential high yields, conventional methods have been used for its extraction, purification and drying. Wet milling is the most common and simple conventional method, using at industrial level, simple equipment and heavy investment, depending on the desired final product (Lundy, Ostertag, & Best, 2002). Cassava starch can be obtained from fresh roots or its non-edible parts, stems, peels and leaves, primarily by wet milling and starch has also been produced from dry cassava chips. The complete step-wise process (using simple or large scale extraction) can be divided into four main stages: (i) preparation (peeling and washing); (ii) rasping/pulping/grating; (iii) recovery (starch sedimentation, washing, dewatering, drying); and (iv) finishing (milling and packaging).

Table 1
Composition of sweet cassava root and different components.

Component	Per 100 g (On a fresh weight (dry matter) basis)	
Cassava root (Uchechukwu-Agua, Caleb, & Opara, 2015)		
Water, g	60	
Protein, g	1.4	
Fat, g	0.28	
Carbohydrate, g	38	
Fibre, g	1.8	
Sugar, g	1.7	
Minerals, g	0.46	
Vitamins, g	0.07	
Cassava peeled & unpeeled root (Ospina & Ceballos, 2002)		
	Peeled	Unpeeled
Water, g	71.50	68.06
Carbohydrate, g	26.82	29.06
Crude fibre, g	0.12	0.99
Crude protein, g	0.74	0.87
Ash, g	0.13	0.17
Vitamins	0.69	0.85
Cassava waste solids (peel and edible fibre) polysaccharides (Salvador, Suganuma, Kitahara, Tanoue, & Ichiki, 2000)		
Others	1.8	
Pectin	17.8	
Hemicellulose	22.8	
Cellulose	48.2	

Beyond starch extraction, cassava processing also generates large amounts of wastes as waste solids and wastewaters (Adeola, 2011). The United Nations Statistics Division, *Glossary of Environment Statistics* defines wastes as materials that are not prime products for which the initial user has no further use in terms of his/her own purposes of production, transformation or consumption, and of which he/she wants to dispose. Wastes can be generated during the extraction of raw materials, the processing of raw materials into intermediate and final products, the consumption of final products, and other human activities (UNSD, 1997). According to Food and Agriculture Organisation of the United Nations (FAO, 2013), starch roots, mainly cassava contributes over 700 MT wastes in the global upstream food wastes, requiring conversion into valuable products and energy in an environmentally friendly manner. Besides, an active starch plant can generate up to 47% total fresh disposable cassava by-products (Heuzé, Tran, Archimède, Lebas, & Regnier, 2013). When disposed for a given period in the environment, these could be typically associated with emission of strong unpleasant smells, carbon-dioxide and total cyanogens. Cassava wastes -rich total cyanogens can contaminate surface water, groundwater, soil, and air which causes more problems for humans, other species, and ecosystems (Simonetto, de, & Borenstein, 2007). In addition, cassava wastes can also be a source for rodents and insects, which can harbour gastrointestinal parasites, yellow fever, worms, the plague and other conditions for humans. Moreover, the increasing nature of non-beneficial sweet cassava competition might exacerbate waste disposal problems arising from more use of bitter cassava. During the traditional processing, huge waste solids and wastewater are generated from bitter varieties in order to avoid total cyanogens contained in the peels (Cardoso et al., 2005; Tumwesigye, Oliveira, & Sousa-Gallagher, 2016b). With insufficient prioritization of packaging source reduction, recyclability, compostability, recycled content and recycling policies (MacKerron & Hoover, 2015), wastes are likely to increase in the years ahead.

4. Emerging trends for sweet cassava biobased packaging material development and technological challenges

A number of conventional methods/techniques for the development of biobased packaging materials have been reported in literature, and they include: extrusion (sheet/film, reactive), baking, injection moulding, blow moulding, compression moulding, vacuum foaming, casting, spraying, lamination, calendaring and thermoforming (Imam et al., 2008). Casting has been the commonest technique used for producing edible and biodegradable starch films (Table 2), and was adequately described by Jiménez, Fabra, Talens, and Chiralt (2012). Regardless of the technique used, the production and characterisation of BPM is a four-stage process: (i) preheating homogenisation of additives; (ii) heating of polymeric solution; (iii) drying; and (iv) structural and functional characterisation. Heating and drying are vital steps in the production of desired BPM because they can alter the structure and affect the functional application (Tumwesigye et al., 2016b). The most common convention characterisation techniques for cassava reported are: (i) thickness measurements (Micrometer); (ii) optical (colour-chroma;