Food Packaging and Shelf Life 7 (2016) 8–19

Contents lists available at ScienceDirect

Food Packaging and Shelf Life

journal homepage: http://www.elsevier.com/locate/fpsl

New sustainable approach to reduce cassava borne environmental waste and develop biodegradable materials for food packaging applications

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ARTICLE INFO

Article history:
Received 10 August 2015
Received in revised form 20 October 2015
Accepted 14 December 2015
Available online 6 January 2016

Keywords:
Bitter cassava
downstream processing
waste reduction
film development
sustainability

ABSTRACT

Transforming waste cassava into a sustainable resource requires a new approach and redesign of the current processing methodologies. Bitter cassava cultivars have been employed mainly as an emergency famine food, but could also be used as a value added material for packaging. Processing of intact bitter cassava can minimize waste, and produce low-cost added value biopolymer packaging films for targeted applications. This study developed an improved simultaneous release, recovery and cyanogenesis (SRRC) downstream processing methodology for sustainable reduction of waste and development of film packaging material using intact bitter cassava.

SRRC approach produced peeled (BP) and intact (BI) bitter cassava biopolymer derivatives. BI showed significantly higher yields ensuring 16% waste decrease with no environmental impact caused by discard residues. SRRC was very effective in reducing the total cyanogen content to within Codex minimum safety limits, demonstrating that the peeling of bitter cassava process can be avoided. Transparent films were produced using the casting method from both BP and BI derivatives. BI films were more transparent and homogeneous, less soluble, less permeable to moisture, less hydrophilic, more permeable to oxygen and carbon-dioxide, sealable, lower cost, than the BP.

Hence, intact bitter cassava and SRRC can be used as sustainable, safe, integrative process solution for high value-added product (e.g., packaging film) production from low-cost biobased materials.

1. Introduction

The environmental problems caused by food supply chain waste and by-product streams have triggered increased demand for research into biobased value added products and efficient sustainable renewable resources. Thus far, there is a growing realization of the requirement to increase value products that are made out of secondary raw materials. Among these, waste is considered a valuable resource to provide sustainable feedstock and concurrently contribute to circular-based approach of energy recovery (Essel & Carus, 2014).

Cassava (*Manihot esculenta* Crantz) crop is considered among the highest generators of huge amount of wastes in the form of peel, pulp, wastewater and leaves during postharvest processing (FAO, 2013). With increased population, production and consumption of cassava has increased consistently and thus waste disposal in the environment has increased tremendously due to a linear and irreversible behavioral pattern that follows a produce–consume and dispose model. According to 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.

Apart from direct food wastes, other sectors such as foods, beverages and consumer goods packaging generate more non-eco-friendly plastic wastes and this has resulted into huge impact on the environment. 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. It is estimated that less than 14% of plastic packaging materials are recyclable (MacKerron & Hoover, 2015), and as plastic commands the greatest proportion of food packaging industry, the need to design biobased material is a priority.

With increased devotion to research into packaging sustainability, it is highly likely that non-commercial and non-food

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http://dx.doi.org/10.1016/j.fpsl.2015.12.001

plants-derived feedstock will anchor packaging industry. Besides, the finite and dwindling natural material sources and competition for food supply amidst population growth, justify the need to invest into efficient utilization of unexploited resources. Thus, addressing waste minimization and developing packaging materials, in tandem, could result into a more competitive resource efficient economy.

An alternative strategy is to use a circular utilization model whereby cassava waste could be transformed into resource for development of value-added flexible packaging materials resulting in waste minimization due to the biodegradable nature of the materials. If used efficiently, cassava borne environmental wastes have the potential commercial viability in better eco-designing of materials for food and non-food applications. Semi-commercial crops such as bitter cassava (BC) have the potential to sustain the growth of food plastic packaging industry. Like sweet cassava, BC-based films have potential biodegradability and could form excellent film forming properties. However, their demands for processing prior to use due the high total cyanogens (TC) (containing 900–2000 ppm) (Cardoso et al., 2005), has limited their commercial potential. Essentially, when bitter cassava is used as food, the peels are extensively removed resulting in huge contribution to waste generation and even a negative environmental impact. Traditionally, processing is achieved by peel removal, generating great amounts of waste. Nonetheless, elimination of the peelings does not guarantee its safety, reasonable lethal amounts of TC still remain and the roots have to be further processed. Traditional soaking and heaping fermentation methods produce high levels of unspecified total cyanogens combined in waste waters and peels, and deliberate burning of peel wastes contributes to carbon dioxide emission and strong offensive smells to the environment (Heuzé et al., 2015). Using bitter cassava for waste minimization and package development could be done in an efficient manner, which is compatible with increased income and improved safety of cassava dependants and reduced environmental impact, while providing a sustainable feedstock for packaging applications.

Transforming waste cassava into a sustainable resource requires a new approach and redesign of the current processing methodologies. Simultaneous release, recovery and cyanogenesis (SRRC) could be a sustainable approach in processing and has been explored and piloted with success to ease downstream extraction of biopolymers from whole root cassava (Tumwesigye, Oliveira, & Sousa-Gallagher, 2014). Safe and clear biopolymer derivatives have been produced, with success, from the whole root of cassava for potential food and non-food industrial use. The SRRC processing methodology, utilizing semi-commercial intact bitter cassava, could be explored in production of flexible food packaging film materials with improved properties. Moreover, for production of low-cost packages but also by obtaining sustainable feedstock because bitter cassava has no competition with food supply since sweet cassava has normally been utilized as food and non-food materials. Additionally, SRRC is an intrinsic processing methodology which re-enforces starch with compounds from the peel and other waste solids, and there is no generation of wastes and waste streams. This could reduce the cost of film package production and ensure process economy.

The objective of this study was to (i) use intact bitter cassava to reduce waste, (ii) apply an improved systematic downstream processing approach to improve biopolymer derivatives physicochemical properties, and (iii) development of film packaging material. If biopolymer derivatives and films produced out of intact bitter cassava presented comparable or better properties than those made from peeled equivalent, then it would be possible to eliminate the peeling, and its environmental impact, with additional production of flexible packaging material as added value product.

2. Methodology

2.1. Source material

Decisions to source for a sustainable raw material was based on many factors taking into account the renewable resources, no competition with food supply, minimising waste and environmental impact, and cost-effective option. Accordingly, bitter cassava (Tongolo) was the preferred material used for package development.

2.1.1. Cassava preparation

Bitter cassava roots (Tongolo) at 12–18 months were picked from farmers' fields (Northern Uganda) according to recommended harvesting practices (CODEX, 2013). The roots were separated from soil debris, placed in ice boxes, transported to the laboratory and kept at −20 °C for further treatment. Fresh bitter cassava was assessed for total cyanogen content immediately after harvesting and prior to pulp preparation. The cyanide kit A from Australian National University (Canberra) was used for determination of hydrogen cyanide in fresh cassava as described (Bradbury, Egan, & Bradbury, 1999).

2.1.2. Waste solid analysis

Bitter cassava was used intact (I) or peeled (control), washed thoroughly, rinsed 3 times with deionized water and kept at −20 °C between sample extractions.

Waste solids quantification was done by randomly selecting 12 intact roots from the bulk bitter cassava. The wastes (peel, cambium, phloem, central xylem fiber) were carefully removed from the parenchyma, and both peel and peeled root portions were separately weighed. Each measurement was taken from 100 g intact roots that were correspondingly assigned to 9 different treatments during subsequent tests. The weight of the waste solid was calculated by dividing the weight of waste by the weight of intact root and expressed as a percentage.

2.2. Simultaneous release, recovery and cyanogenesis (SRRC) of biopolymer derivatives

The downstream processing procedure is schematically presented in Fig. 1. Both intact and peeled roots were processed in two-stages, the mechanical tissue rupture and the biopolymer release, in order to obtain biopolymer powders. In elucidating the function of simultaneous release, recovery and cyanogenesis (SRRC) in downstream processing, intact (I) (periderm-free) roots were scrubbed, while in the peeled (P) (cortex-free) roots, the peel was manually and carefully detached from the edible portion (parenchyma). Intact and peeled bitter cassava roots were fed into an automated grating machine and the resulting pulp mass obtained after mechanical tissue rupture and cell disruption. The machine was equipped with a feeding hopper, a constant speed rotating perforated spiked drum and an inclined delivery channel. This initial action serves the dual purpose of activating cyanogens hydrolysis into release of volatile hydrogen cyanide and bringing together different polymer components for possible modification.

Biopolymer derivatives release and recovery was performed by adding 100 g of pulp mass into 100 ml of extraction buffers in a commercial blender (500 W Breville IHB086Hand Blender). Full factorial design of 9 different solutions, i.e., 2 extraction buffers at 3 levels, NaCl (0, 1.5, 3.0 M) and H_2SO_4 (0, 25, 50 mM) were used. A total of 18 different samples (9 Intact and 9 peeled cassava roots) were then homogenized, filtered, centrifuged and washed in deionized water (Fig. 1). The chemicals used in release and recovery, i. e., sodium chloride (≥99% AR), conc. sulphuric acid