Journal of Food Engineering 104 (2011) 639–648

Contents lists available at ScienceDirect

Journal of Food Engineering

journal homepage: www.elsevier.com/locate/jfoodeng

Physical and chemical properties of ultrasonically, spray-dried green banana (*Musa cavendish*) starch

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ARTICLE INFO

Article history:
Received 10 November 2010
Received in revised form 28 January 2011
Accepted 1 February 2011

Keywords:
Green banana
Spray dryer
Ultrasound
Starch

ABSTRACT

Ultrasonic wave propagation and the spray dryer technique were applied to study their effect on the physical and chemical properties of green banana starch. The results showed high resistant starch content, which was reduced by ultrasound treatment and also by spray drying. Both techniques increased the solubility, swelling power and water absorption capacity. The gels exhibited non-Newtonian shear-thinning behavior, since flow behavior index was less than one ($n < 1$). Ultrasound wave propagation reduced yield stress and consistency coefficient in starch gels. Under oscillatory shear, all gels exhibited solid-like viscoelastic behavior, storage modulus was higher than loss modulus to entire frequency range ($G' > G''$), which was confirmed by the Cox–Merz experiment that showed that the complex dynamic viscosity was greater than the apparent viscosity in all samples. The gelatinization temperature was mainly influenced by drying technique and ultrasound treatment reduced the amount of energy required to gelatinize the starch.

1. Introduction

Seven million tons of Brazilian bananas are produced every year, which corresponds to 7.8% of worldwide production (FAO, 2010). During banana commercialization and post-harvest handling in Brazil, large quantities of this commodity are lost due to the fact that the banana is a climacteric fruit and the Brazilian habit of consuming ripe fruit. According to the banana's Producers Association, 40% of production in Brazil is lost to failure because of farming until marketing and most types of production are intended for *in natura* consumption (Izidoro, 2007). Losses can be reduced by the processing of rejected fruits and the utilization of green banana pulp, which contains 70–80% starch on a dry weight basis. Furthermore, banana starch is a potentially resistant starch (RS) source.

The relatively recent recognition of incomplete digestion and absorption of starch in the small intestine as a normal phenomenon has raised interest in nondigestible starch fractions (Cummings and Englyst, 1991). These are called "resistant starches" and extensive studies have shown them to have physiological functions similar to those of dietary fiber. RS is now defined as that fraction of dietary starch, which escapes digestion in the small intestine (Sajilata et al., 2006).

Green bananas are known to present resistant starch type II (RS_2), in raw starch granules, RS_2 is tightly packed in a radial pattern and this compact structure limits the accessibility of digestive enzymes and accounts for its resistant nature (Almeida, 2009).

One factor that affects their resistance to digestion is processing conditions and the diversity of the modern food industry allied to the enormous variety of food products it produces require starches that can tolerate a wide range of processing techniques and preparation conditions (Visser et al., 1997).

The starch market is growing rapidly, and starch products are currently used for many applications in food processing to achieve particular physical properties, such as solubility, viscosity, digestibility, swelling and pasting (Jambrak et al., 2010). Changes in the technological properties of starch can be obtained by physical (thermal treatment, radiation exposure), chemical and enzymatic processes. Spray drying can also alter the starch product depending on atomization characteristics such as liquid atomization, liquid contact with hot air, water evaporation and powdered air drying separation (Tonon et al., 2008).

Another option for modifying starches is sonication, which consists of treatment of the polymer with ultrasound. Ultrasound is generated with either piezoelectric or magnetostrictive transducers that create high-energy vibrations. These vibrations are amplified and transferred to a sonotrode or probe, which is in direct contact with the fluid. This promising technique is usually performed in

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doi:10.1016/j.jfoodeng.2011.02.002

Nomenclature

G'	Storage modulus
G''	Loss modulus
G^*	Complex dynamic viscosity
K	Consistency coefficient (Pas^n)
n	Flow behavior index of the fluid (dimensionless)

Abbreviations

AMG	Amyloglucosidase
DSC	Differential Scanning Calorimetry
d.b.	Dry basis
FAO	Food and Agriculture Organization of the United Nations
GBS A	Green banana starch dried in a conventional oven
GBS B	Green banana starch dried in a spray dryer
GBS C	Green banana starch with ultrasound frequency/dried in a conventional oven
GBS D	Green banana starch with ultrasound frequency/dried in a spray dryer
GOPOD	Glucose oxidase/peroxidase reagent
R^2	Determination coefficient
RS	Resistant starch
RS_2	Resistant starch type II
S	Solubility
SP	Swelling power
SSR	Sum of squared residuals
T_p	Gelatinization temperature
T_i	Initial gelatinization temperature
T_f	Final temperature
WAC	Water absorption capacity

Greek symbols

η_{ap}	Apparent shear viscosity (mPa s)
η^*	Complex dynamic viscosity (mPa s)
τ_o	Yield stress (Pa)
τ	Shear stress (Pa)
γ	Shear rate (s^{-1})
ΔH	Gelatinization enthalpy
tan δ	Tan delta
ω	Frequency of oscillation (rads^{-1})
χ^2	Chi-square

aqueous solutions (in the case of polysaccharides) and in suspensions (Czechowska-Biskup et al., 2005; Jambrak et al., 2010).

Additionally, examination of the rheological properties of starches is an important step in the characterization and understanding of their functional properties. Some banana starch properties have been investigated in several studies by Bello-Pérez et al. (2000), Waliszewski et al. (2003), Núnez-Santiago et al. (2004), de La Torre-Gutiérrez et al. (2008) and Izidoro et al. (2008). Nevertheless, there is no study reporting the application of ultrasound in green banana starch. The aim of this work was to investigate the physical and chemical properties of green banana starch dried using a conventional oven or a spray-dryer combined with cyclic sound pressure (ultrasound) treatment.

2. Materials and methods

2.1. Raw material analysis

Green bananas of the 'Nanica' (*Musa cavendish*) variety that came from Corupá region (Santa Catarina) and were obtained from Central Supply SA in Curitiba (Brazil). This variety was chosen for its great production and availability in Brazil. Physico-chemical and firmness analysis were conducted on fruits, previously selected and washed, for maturation stage characterization. Moisture, pH, titratable acidity (expressed in molarity of malic acid) and total soluble solids were determined according to the Instituto Adolfo Lutz (IAL) (2005) methodology.

A TA-XT2i texture analyzer (Stable Micro Systems, Godalming, UK) was used to evaluate banana firmness (N). Fifteen bananas were selected to firmness analysis and penetrometer tests were performed on whole banana pulp at the center side. The plunger was a cylinder of 6 mm in diameter (P/6 model). Fruit penetration velocity was 1.0 mm s^{-1} and penetrated up to 20 mm deep (Tribess and Hernandez-Uribe, 2009).

2.2. Starch isolation

Starch was obtained according to the Sánchez-Hernandez, 1999) and Whistler (1998) methodologies. Green bananas were washed, peeled and cut into cubes. To avoid enzymatic browning, the cubes were processed in a bisulfite solution (1%; 1:2 w/v) using an industrial blender (LTA-2 n 275; Metallurgical Becker Industrial Equipment; SC) at 22000 RPM for 5 min. After the processing, the solution was filtered through sieves of 35, 48, 100, 150 and 200 mesh. The residue was washed several times with water. The obtained solution (200 mesh) was then centrifuged (Sigma Laboratory Centrifuges; k-15CO) at 7000 RPM for 30 min. The supernatant was carefully removed, and the decanted mass was washed and centrifuged again. The supernatant was removed, and the decanted mass was divided into four portions (because the starch samples were dried using different conditions) including: a conventional oven (GBS A), a spray dryer (GBS B), a conventional oven with ultrasound treatment (GBS C) and a spray dryer with ultrasound treatment (GBS D).

2.2.1. Ultrasound pretreatment

A piezoelectric apparatus equipped with a VCX probe system (model 500, SONICS (Connecticut, USA)) was used for ultrasound treatment. The solutions were placed in 500-mL beakers, and the starch solution concentration was 20 g L^{-1}. This is maximum concentration recommended by the manufacture to avoid the probe abrasion.

An exchangeable tip probe was used. The probe (vibrating titanium tip of 19 mm in diameter) was attached to the transducer, and it was immersed in a suspension that was irradiated with an ultrasonic wave directly from the horn tip. The ultrasound application time was 1 h with pulsations in the range of 1 min. The ultrasound power was 24 W with 40% amplitude at a frequency of 20 kHz. After application of the ultrasound, the suspension was then centrifuged at 7000 RPM for 30 min. The supernatant was discarded, and the decanted starch was dried according the Section 2.2.2.

2.2.2. Drying process

The drying processes of the starches were carried out as follows. (a) A MSD 1.0 model mini spray dryer (LM Labmaq, Brazil) with an inlet temperature of 130 °C ± 5 and outlet temperature of 47 °C ± 5 was used with a 15% starch solution. The flow speed was set at 0.75 L h^{-1}, the air drying flow rate was 0.6 m^3 min^{-1} and the compressed air flow was 30 L min^{-1}; (b) a conventional oven at 50 °C was used to dry the starch for a period of 4 h. The dried starch collected was weighed, labeled and stored.