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ORIGINAL RESEARCH

Which one is important to achieve maximum degree of hydrolysis, starch pre-treatment or activated α-amylase: kinetics and mathematical modeling for liquefaction

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Abstract
To determine whether starch pretreatment or enzyme modification is more effective in achieving maximum hydrolysis, corn starch (CS) as a A-type starch and potato starch (PS) as a B-type starch were pre-treated using freezing–thawing (FTF), ultrasonication (US), high-pressure (HP). On the other side, α-amylase was activated with concomitantly applying dual frequency ultrasound (25 + 40 kHz) and Ca^{2+} ions. The effect of starch pre-treatment and enzyme modification on the starch digestion behavior were investigated. Freeze-thawed, ultrasonicated, and high-pressurized starches are highly more susceptible to amylolysis than native ones due to higher amount of disordered structure in the disrupted granules (based on crystallinity structure (determined by X-ray) and formation of hole and crack on the surface of pre-treated starches (determined by SEM analysis). Starch hydrolysis kinetics were evaluated using the first-order equation. Comparing the maximum hydrolyzed concentrations (C_∞) and reaction rate constants (k) of pre-treated potato starches indicated that PFTP starch was most affected by a specific enzyme whereas for the pre-treated corn starches, these values were higher in pressurized corn starch. An inverse linear correlation has been shown between ordered structure and the rate of enzyme binding. Concerning to Pareto chart, the starch type depicts a greater influence on the degree of hydrolysis (%) than the other factors. Moreover, activated enzyme and starch pre-treatment represented the same standardized effects on achieving maximum hydrolysis degree.

Keywords Hydrolysis efficacy · Freezing–thawing · Dual frequency ultrasonication · High-pressure · Hydrolysis kinetic

Introduction

As a common component in the human diet, starch has been widely utilized in the food (as a thickening, stabilizing, texturizing, gelling and anti-caking agent) and non-food (medicine, textile, paper, fine chemicals, petroleum engineering and agriculture) industry. Despite myriad usages of native starches, they are modified to improve their defections including insolubility in cold water, poor heat resistance, low digestion resistance, and low shear stress. To improve the starch structure and to fit the requirement of modern industrial processing, chemical, physical and biochemical modifications are applied for starch modification [1].

Various kinds of dual modification can be classified into four, i.e., dual physical, dual enzymatic, dual chemical, and dual heterogeneous changes because it seems more important than other forms of single modifications [2].

Enzymatic modification by α-amylases (α-1,4 glucan-4-glucanohydrolase, EC 3.2.1.1) potentially cleave the internal α-1,4-glycosidic linkages in starch's amylose and amylopectin chains. Thereby, starch liquefaction can be proceeded and produced mixture of simple carbohydrates including high-glucose or fructose syrup, maltose, oligosaccharides, and other products like bioethanol which can be used in the food and non-food industry with better functional properties [3]. Moreover, the rate of starch hydrolysis is important to human health due to the impact on the plasma insulin level and energy metabolism [4]. In this regard, the efficiency of

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