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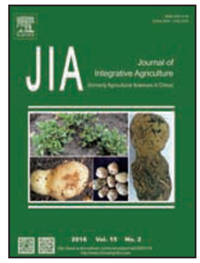

RESEARCH ARTICLE

Effects of high temperature during grain filling on physicochemical properties of waxy maize starch

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Abstract

Understanding the waxy maize starch physicochemical properties response to heat stress during grain filling could improve starch quality. The effects of heat stress during early (1–15 days after pollination, DAP) and late (16–30 DAP) grain filling stages on the starch physicochemical properties of four waxy maize varieties were evaluated. Crystallinity only increased in Suyunuo 5 after exposure to high temperature at late grain filling stage. The effects of heat stress on digestibility and swelling power were dependent on varieties and stages. Generally, swelling power was increased by heat stress at early grain development stage and digestibility was increased by high temperature at late grain filling stage, respectively. The results of correlation analysis indicated the starch with large granule size could swell well and easy digest. Peak, trough, final, and breakdown viscosities in response to heat stress were dependent on stages and varieties. In general, peak, trough and final viscosities were decreased and increased by heat stress at early grain formation and late grain filling stages, respectively; whereas the breakdown and setback viscosities were similar among the three treatments. Heat stress increased the gelatinization temperatures and retrogradation percentage. Gelatinization range decreased under heat stress at 1–15 DAP but remained constant under heat stress at 16–30 DAP in all varieties. The starch exposed to high temperature at 16–30 DAP presented higher digestibility and peak viscosity and lower retrogradation percentage than those at 1–15 DAP. Therefore, heat stress at early grain formation stage severely affects the physicochemical properties of starch.

Keywords: waxy maize, heat stress, digestibility, pasting, gelatinization, retrogradation

1. Introduction

Global warming is irreversible. The changes in the concentrations of carbon dioxide and other greenhouse gases have increased global surface air temperatures by approximately 0.8°C over the last century, and the global temperature is predicted to increase by 1.8 to 4.0°C at the end of this century (IPCC 2007). For the next 40–70 years, the increasing seasonal temperature will exceed the most extreme seasonal temperatures recorded from 1900 to 2006; high seasonal temperature will become widespread and will strongly affect agricultural productivity and food security (Battisti and Naylor 2009). Heat stress affects the grain yield and the relative physiological and biochemical properties of maize (Prasad *et al.* 2008; Crains *et al.* 2012; Hasanuzzaman *et al.* 2013). Lobell *et al.* (2013) observed that maize yield is negatively correlated with

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the accumulation of temperature higher than 30°C or with extreme-degree days. An increment of 2°C can result in 10% or higher yield loss (Lobell and Burke 2010).

Grain filling stage is the critical stage for grain yield and quality formation. Heat stress during this stage can strongly affect grain quality. Lu *et al.* (1996) demonstrated that starch granule size and true amylose content decrease under heat stress after pollination, resulting in the increase in gelatinization temperature; moreover, the effects on the granule shape and distribution of various branch-chain fractions of starch are variety dependent. Zhong *et al.* (2005) observed that heat stress after pollination increases the gelatinization temperature of rice flour, whereas amylose content, pasting properties and X-ray diffraction intensities at different peaks response to heat stress depend on varieties. Liu *et al.* (2011) found that 3-d heat stress at different stages after anthesis decreases the starch and amylopectin contents and the ratio of the large to small granules. The effects of heat stress at early stages after anthesis are more critical to starch formation and flour pasting properties than those of heat stress at the late stages (Zhang *et al.* 2006; Liu *et al.* 2011; Lu *et al.* 2013). Grain initiation and early grain filling are sensitive cell physiological and biochemical process required for organ establishment (Beckles and Thitisaksakul 2014). Moreover, heat stress during grain filling increases protein content, decreases starch content and changes the starch physicochemical properties (Prasad *et al.* 2008; Wang and Frei 2011; Crains *et al.* 2012; Thitisaksakul *et al.* 2012; Beckles and Thitisaksakul 2014). Our previous studies showed that heat stress after pollination affect the starch structure and thermal properties of waxy maize (Lu *et al.* 2014). Moreover, heat stress at the early stage after pollination has more severe effects on grain yield and quality than that at the late stage (Lu *et al.* 2013). In the present paper, we reported the effects of heat stress at different stages after pollination on the physicochemical properties of starch.

2. Results

2.1. Crystallinity

Heat stress at 1–15 or 16–30 days after pollination (DAP) did not affect the X-ray diffraction pattern of waxy maize starch and all samples present typical A-type diffraction pattern (data not shown). Heat stress at 1–15 DAP did not affect the crystallinity of all varieties. After the plants were exposed to high temperature at 16–30 DAP, crystallinity only increased in Suyunuo 5 but remained constant in the other three varieties (Fig. 1).

2.2. Swelling power

The effects of high temperature after pollination on swelling power were dependent on heat stress stages and varieties (Fig. 2). Heat stress at 1–15 DAP increased the swelling power in Lainongnuo 11 but not in the other three varieties compared with the control. Moreover, heat stress at 16–30 DAP did not affect the swelling power in Suyunuo 5 and Huaikenuo 3; however, the swelling power in Yunuo 7 decreased and that in Lainongnuo 11 increased under this treatment. Generally, swelling power was similar between the control (16.2 g g^{-1}) and heat stress at 16–30 DAP (16.1 g g^{-1}) but increased after exposure to high temperature at early grain formation stage (19.1 g g^{-1}). The swelling power was observed with the average granule size (r=0.59, P<0.01), indicating that starch with large granule size swell better than small ones (data of average granule size from Lu *et al.* 2013).

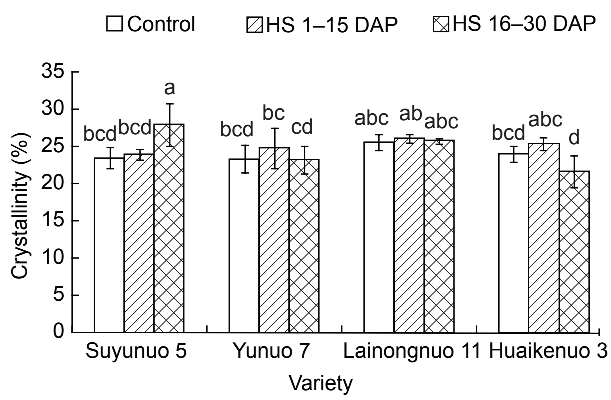

Fig. 1 Effects of heat stress during early and late grain filling stages on the crystallinity of waxy maize starch. DAP, days after pollination. Bars are means±SE. Mean values followed by different letters are significantly different (P<0.05). The same as below.

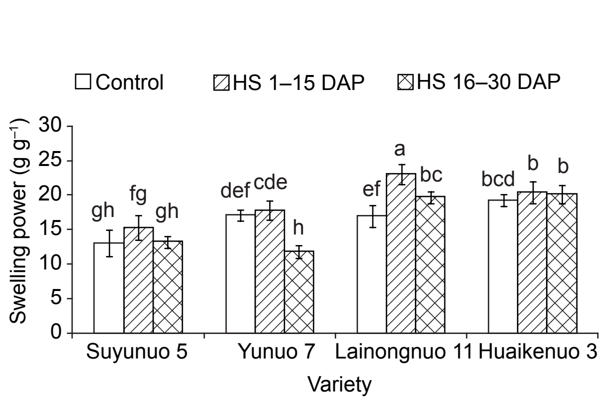

Fig. 2 Effects of heat stress during early and late grain filling stages on the swelling power of waxy maize starch.