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# Correlation between the lignin content and mechanical properties of waxy corn pericarp

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ABSTRACT

The pericarp mechanical properties of waxy corn inbred lines are important factors of pericarp, which was one of the most important factors affecting the fresh corn eating quality. This study investigated the correlation between the lignin content and pericarp thickness of 10 waxy corn inbred lines and their mechanical properties of rupture force, breaking length and tensile energy absorption. Based on correlation coefficients, a strong negative correlation was found between the lignin content of all waxy corn inbred lines studied and their mechanical properties. The correlation levels between the lignin content and rupture force, breaking length and tensile energy absorption were $r = -0.88$, $-0.91$, and $-0.75$ for cooked samples and $r = -0.63$, $-0.62$, and $-0.75$ for fresh samples, respectively. The mechanical properties of pericarp had positive correlation with eating quality. However, there were no significant correlation between the pericarp thickness and eating quality score. The pericarp thickness may not be the main factor affecting fresh corn eating quality.



## 1. Introduction

Waxy corn was found in China in 1909. The endosperm of waxy maize contained only amylopectin and no amylose starch molecule in opposition to normal dent maize varieties that contain both. For waxy corn, a single recessive gene (*wx*) was located on the short arm of chromosome 9, codes for the waxy endosperm of the kernel (Collins, 1909), Modified waxy maize starches are used for the improvement of uniformity, stability, and texture in various food products. Waxy maize starch is also the preferred starting material for the production of maltodextrins because of improved water solubility after drying and greater solution stability and clarity (Sprague, 1939). But fresh waxy corn was also a very popular food in Asian countries such as in China, Korea, Japan and Philippines. The waxy corn consumption has increased a lot in the last decade especially for the fresh waxy corn. The fresh waxy corn consumption is similar to that for sweet corn, at about 25 days after pollination. People enjoy waxy corn for its tenderness and stickness (Kim et al., 1994). Just like sweet corn, the eating quality of fresh waxy corn is also determined by flavor, texture, and aroma (Flora and Wiley, 1974). Due to the particular desired taste and sensory traits of fresh waxy corn, which has much more sticky and starchy texture than sweet corn, the waxy corn breeding is mainly focused on tenderness (Kim et al., 1994). The texture was generally thought to be the creaminess of the kernel. The maize endosperm types played an important role in texture. The endosperm had great effect on the eating quality of waxy corn. Most of the waxy corn had nearly same amylopectin content. Hence it is difficult to improve waxy corn eating quality by changing texture or improving amylopectin content. Besides endosperm texture, pericarp thickness had been identified as an important factor to improve the consumer's score of eating quality (Culpepper and Magoon, 1927). Pericarp tenderness has been defined as the predisposition of the pericarp to fragmentation by chewing (Huelson, 1954). Early studies indicated that pericarp thickness is negatively correlated to the pericarp tenderness (Ito and Brewbaker, 1981; Tracy and Galinat, 1987; Bailey and Bailey, 1938).

The mechanical properties are very important agricultural traits in plant (Mehmet et al., 2012). Brittle mutation is a common mutation in plants such as Arabidopsis (Turner and Somerville, 1997), barley (Kokubo et al., 1989, 1991; Burton et al., 2010), maize (Musel et al., 1997) and rice (Qian et al., 2001; Li et al., 2003; Wang et al., 2006). Previous studies determined the plant brittleness related to lignin contents of cell wall (Turner and Somerville, 1997; Kokubo et al., 1989, 1991). Li et al. (2003) reported that the rice brittle mutant *bc1* gene encodes a cobra-like protein which lading to the decrease of cellulose and increase of lignin contents. Sindhu et al. (2007) reported that maize *brittle stalk2* encodes a cobra-like protein expressed in early organ development but required for tissue flexibility at maturity, which result in the maize

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cellulose decreased, while lignin contents increased a lot. The pericarp mechanical properties of waxy corn inbred lines are important factors of pericarp tenderness, which affecting the fresh corn eating quality (Teri et al., 2004). These properties are also important parameters for breeders to screen inbred lines with brittle pericarp. In this study, the waxy corn brittle pericarp mutant had much tenderness and better eating quality than wild type, but other phenotypes, amylopectin and amylose content did not have significant differences. The brittle pericarp had low rupture force, breaking length and tensile energy absorption and it was good pericarp trait to improve waxy corn eating quality. Rupture force, breaking length and tensile energy absorption are important mechanical properties of waxy corn pericarp. Rupture force is the minimum force needed to rupture the pericarp. Breaking length is the maximum length of a certain sample ruptured due to its own gravity. Tensile energy absorption is the energy required during the pulling to rupture the sample pericarp (Sirisomboon et al., 2007). Several studies have been studied the mechanical properties of wheat. Kang et al. (1995) analyzed the mechanical properties of wheat, such as yield stress, modulus of deformability and energy to yield point. Dobraszczyk et al. (2002) studied the fracture properties of wheat endosperm. Babic et al. (2011) analyzed mechanical properties of 3 wheat varieties. The literature also includes the mechanical property study on plant products such as sunflower (Gupta and Das, 2000), corn (Seifi and Alimerdani, 2010; Kalkan et al., 2011).

The mechanical properties of several grains had recently been reported. The correlations between the protein content and mechanical properties are also studied (Mehmet et al., 2012). However, pericarp mechanical properties had not been studied and published studies about the correlation between the pericarp lignin content, pericarp thickness and mechanical properties of waxy corn do not exist. The objective of the work is to determine the correlation between the pericarp lignin contents, pericarp thickness and mechanical properties of rupture force, breaking length and tensile energy absorption.

## 2. Materials and methods

### 2.1. Plant materials and experiment design

A total of 10 inbred lines of waxy corn with different pericarp thickness and tenderness were selected as study materials, namely, Shen nuo STK, Shen nuo F zi, Shen nuo Z zi, Shen nuo zi cui, Shen nuo 232, Shen nuo 350, Shen nuo 610, Nuo 1, Shen nuo 509 and Shen nuo 612, which provided by Specialty Corn Institute of Shenyang Agricultural University. Shen nuo STK, Shen nuo F zi, Shen nuo Z zi, Shen nuo zi cui were newly bred inbred lines, and Shen nuo zi cui was the brittle mutant with brittle pericarp which tasted more tenderness than other inbred lines. While Shen nuo 232, Shen nuo 350, Shen nuo 610, Nuo 1, Shen nuo 509 and Shen nuo 612 were inbred lines of commercial waxy corn hybrids in China with different pericarp thickness and tenderness. All of the waxy corn inbred lines were planted in sandy loam soil on 1 May, 2013, at the Shenyang agricultural university research and education center. Each inbred lines was replicated three times with plots consisting of four rows, 6 m long, 0.6 m between rows, and 31.7 cm between plants. Recommended herbicide and pesticide regimens were followed field practices.

### 2.2. Eating quality score

Twenty-five ears were taken from each plot at 25 day after pollination. Ten uniform ears per inbred lines were selected for the taste panel. Cobs were cut into 5 cm sections from the center portion using a portable band saw to prevent crushing sample kernels. Then these cobbettes were stored in a deep freezer at −20 °C. The taste panel consisted of 7 fresh corn breeders. Cobbettes were thawed at room temperature for 1 h prior to being cooked in a steamer in boiling water for 15 min. Cobbettes were immediately removed from the steamer and placed in a container with lid to maintain heat until given to panelist. Panelist were asked to rank the eating quality of each inbred line, which 1 represented the best eating quality, 2 represented the second better eating quality and so on, while 10 represented the worst eating quality. The average panelist scores indicate the tenderness scoring. The smaller scores indicated the better eating quality. Five uniform ears were selected for pericarp thickness measurement.

### 2.3. Pericarp thickness and lignin content

The cooked and fresh samples were stored in FAA fixative (i.e., formalin–alcohol–glacial acetic acid, 90:5:5 by volume). The pericarp thickness of the middle portion of grain germinal side was hand-sliced with a razor blade removing out the extremely thin seed coat and then to be measured using B203 Binocular biological microscope with ocular micrometer (Chongqing Optec Instrument Co., Ltd). The lignin content was determined according to the method of Zwiazek (1991).

### 2.4. Pericarp mechanical properties

The mechanical properties of the waxy corn pericarp were determined using WZL-30B horizontal computer tension meter (Hangzhou Qingtong & Boke Automation Technology Co., Ltd). The germinal side of pericarp middle portion was cut into 5 mm width and positioned on the two sides of the device. The moving chuck moved with a fixed speed of 130 mm $min^{-1}$, pulling the pericarp between the 2 chucks until it fractured. The values of rupture force, breaking length and tensile energy absorption were recorded on the data acquisition board of the tension meter.

### 2.5. Data analysis

Microsoft Excel software was used for data processing and mapping and SPSS12.0 Software was used to analyze significance. $P < 0.01$ was considered as statistically significant at 1%, $P < 0.05$ was considered as statistically significant at 5%.

## 3. Results

### 3.1. Lignin content, pericarp thickness, eating quality and mechanical properties of waxy corn pericarp

Maize pericarp thickness was about 40–250 μm and the pericarp cell layer was about 2–18 layers (Galinat and Chandravadana, 1977). Georgiev (1978) reported that the pericarp thickness of 194 maize hybrids was 48–122 μm, while the pericarp thickness of 79 maize inbred lines was 42–124 μm. In this study the cooked sample pericarp thickness of 10 waxy corn inbred lines were 23.4–70.3 μm, while the fresh sample pericarp thickness were 47.4–92.6 μm (Table 1). The pericarp thickness of cooked sample was lower than fresh sample. The pericarp thickness of cooked sample Shen nuo zi cui had the lowest pericarp thickness. The pericarp lignin content of Shen nuo F zi was the highest of all the waxy corn inbred lines, while Nuo 1 and Shen nuo 610 were the lowest. Table 2 showed the rupture force, breaking length and tensile energy absorption values of the waxy corn inbred lines for both the fresh and cooked samples. The rupture force values of Shen nuo STK, Shen nuo F zi, Shen nuo Z zi, Shen nuo zi cui, Shen nuo 232, Shen nuo 350, Shen nuo 610, Nuo 1, Shen nuo 509, Shen nuo 612 for the cooked and fresh samples were 0.92 and 1.62, 0.52 and 1.47, 0.74 and 2.02, 0.71 and 1.13,