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Evaluation of the chemical quality traits of soybean seeds, as related to sensory attributes of soymilk

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ABSTRACT

The soybean seed chemical quality traits (including protein content, oil content, fatty acid composition, isoflavone content, and protein subunits), soymilk chemical character (soluble solid), and soymilk sensory attributes were evaluated among 70 genotypes to determine the correlation between seed chemical quality traits and soymilk sensory attributes. Six sensory parameters (i.e., soymilk aroma, smoothness in the mouth, thickness in the mouth, sweetness, colour and appearance, and overall acceptability) and a seven-point hedonic scale for each parameter were developed. Significant positive correlations were observed between overall acceptability and the other five evaluation parameters, suggesting that overall acceptability is an ideal parameter for evaluating soymilk flavour. The soymilk sensory attributes were significantly positively correlated with the characteristics of the glycinin (11S)/beta-conglycinin (7S) protein ratio, soluble solid, and oil content but negatively correlated with glycitein and protein content. Our results indicated that soymilk sensory attributes could be improved by selecting the desirable seed chemical quality traits in practical soybean breeding programs.

1. Introduction

The soybean has long been a staple of the human diet in Asia, especially the soyfood such as soymilk or tofu (Liu, 1997). Soy protein is the most inexpensive source of high-nutritional quality protein and therefore is the world's predominant commercially available vegetable protein. Additionally, several putative health-beneficial substances (e.g., isoflavone, saponin, oligosaccharide, phospholipid, polypeptide and dietary fibre) have been identified in soybeans, leading to an increased interest in and demand for soybean and soy-based products. Soymilk is a popular beverage with abundant vegetable protein in Asian countries. As a nutrient-rich beverage, soymilk consumption has sustained a growth rate of 21% per year in the U.S. (Wrick, 2003). However, soymilk is still considered unpleasant to teenagers and Western consumers due to its off-flavour, especially its bitter taste, as well as its beany and rancid flavour (Damondaran & Kinsella, 1981; Wrick, 2003).

Two types of off-flavour in soymilk have been reported. The volatile beany and herbal flavour is composed of the aldehydes, alcohols, ketones, and furans (Kaneko, Kumazawa, & Nishimura, 2011; Wang, Dou, Macura, Durance, & Nakai, 1998; Wilkens & Lin, 1970), whereas the nonvolatile bitterness and astringency consist of phenolic acid, isoflavone, saponin, tetrol, and other substances (Heng et al., 2006; Kudou et al., 1991). The off-flavour development in soymilk is primarily due to the lipoxygenase or the oxidative rancidity of unsaturated fatty acids (Gardner, 1985; Lee, Min, Choe, & Min, 2003; Wolf, 1975). It was reported that plant lipids are sequentially degraded into volatile and nonvolatile compounds by a series of enzymes via the lipoxygenase pathway, which catalyses the hydroperoxidation of polyunsaturated fatty acids containing a 1,4-cis,cis-pentadiene structure to form the medium-chain-length aldehyde and alcohols that are responsible for the grassy-beany flavour (Iassonova, Johnson, Hammond, & Beattie, 2009; Moreira, Tavares, Ramos, & De Barros, 1993; Wolf, 1975). Otherwise, singlet oxygen oxidation could also cause off-flavours due to the oxidation of polyunsaturated fatty acids, as well as the decomposition of vitamin D, riboflavin, and ascorbic acid in foods (Jung, Yoon, Lee, & Min, 1998; Lee et al., 2003; Min & Boff, 2002). Singlet oxygen oxidation is notably rapid in foods containing compounds with double bonds due to the low activation energy for the chemical reaction (Min & Boff, 2002). In addition, singlet oxygen oxidation with linoleic acid is approximately 1,450 times faster than ordinary triplet autoxidation with linoleic acid (Bradley & Min, 1992). Unfortunately, the off-flavour compounds are highly difficult to remove from soymilk processing due to these compounds' high affinities with the soy protein

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(Gkionakis, David Anthony Taylor, Ahmad, & Heliopoulos, 2007; O'Keefe, Resurreccion, Wilson, & Murphy, 1991; Zhou, Boatright, Johnson, & Reuber, 2002).

The flavour property of soymilk is affected by many factors, such as the genotype of soybean cultivars, the processing method, and environmental conditions. Moreover, the soybean seed chemical quality properties—including protein and oil content, fatty acids, isoflavones, saponins, oligosaccharide and peptides—can affect the soymilk flavour attributes significantly (Kudou et al., 1991; Min, Yu, Yoo, & Martin, 2005; Terhaag, Almeida, & Benassi, 2013). Owing to soymilk's off-flavour, many efforts have been taken to improve soymilk flavour based on the selection of soybean cultivars and enhancement of the processing technology (Hildebrand & Hymowitz, 1981; Kwok, Liang, & Niranjan, 2002; Suppavorasatit, Lee, & Cadwallader, 2013). However, the adjustment of processing may lead to a risk of protein denaturation and nutrition destruction in soymilk (Kwok et al., 2002). Therefore, it is necessary to select specific soybean cultivars suitable for soymilk processing in soybean breeding programs.

Taken together, Soymilk is a popular beverage in Asian countries. Additionally, soymilk and its products are regarded as nutritious and cholesterol-free health foods, with considerable potential application. However, information regarding soymilk sensory evaluation and the effect of soybean seed chemical quality traits on soymilk sensory attributes were notably limited (Poysa & Woodrow, 2002; Terhaag et al., 2013). As a result, it is difficult to select suitable cultivars for soymilk processing. Therefore, the objectives of this study were the following: (1) assess the soymilk flavour attributes based on the soymilk sensory evaluation method among 70 soybean genotypes; (2) analyse the correlations between the soymilk flavour attributes and seed chemical quality traits (i.e., protein, oil, storage protein subunits, isoflavones and fatty acids); (3) develop the regression equations for soymilk sensory attributes using soybean seed chemical quality traits; and (4) identify the breeding indexes related to soymilk flavour attributes for soybean quality breeding. This study will improve the standardisation of the soymilk flavour evaluation method and stimulate soybean breeding for improving soymilk flavour.

2. Materials and methods

2.1. Plant materials and field experiments

Seventy soybean genotypes of diverse origins were used in this study, which included 23 Chinese leading cultivars, 14 lines selected from two sets of near-isogenic lines with or without lipoxygenase isozymes (NILs Suzuyutaka from Japan and NILs Century from USA), and 33 advanced lines from representative soybean-producing regions (Table S1). These cultivars were planted at the Changping experimental station (N40°13′ and E116°14′) of the Institute of Crop Science, Chinese Academy of Agricultural Sciences, in 2010 and 2011. Soybean samples were sowed and harvested at the same time. At the experiment's onset, soil pH, all nitrogen, phosphorus, potassium and organic matter levels were 8.22, 80.5 mg kg^{-1}, 68.7 mg kg^{-1}, 14.58 g kg^{-1} and 12.31 g kg^{-1}, respectively. A randomised complete block design in triplicate was employed and the test plots were managed according to the local cropping practice with a row length of 3 m, row spacing of 0.5 m and plant spacing of 0.1 m. Plots were fertilised with 15 t ha^{-1} organic fertilizer, 30 kg ha^{-1} of nitrogen and sufficient phosphorus and potassium during field preparation. Weeds were controlled by the post-emergence application of 2.55 L ha^{-1} of acetochlor, as well as hand weeding during the growing season. Plots were harvested manually when the plants reached physiological maturity. Samples of each soybean genotype were harvested from three plots and analysed for their soymilk flavour attributes and other seed chemical quality traits. Weather data during both years' growing seasons were retrieved from a nearby weather station (Table S2).

2.2. Preparation of soymilk

The soymilk preparation equipment was made of either stainless steel or plastic. The flow diagram of the soymilk preparation process followed the method described by Min et al. (2005). As shown in Fig. S1, 25 g of soybean seeds were rinsed and soaked in 250 mL of distilled water for 10 h at room temperature. The soaked soybean seeds were drained, rinsed, and ground in a Phillips blender (HR2003, Phillips Hong Kong Limited, China) for 1.0 min at high speed with corresponding water to make a total of 500 g of soybean slurry. The ratio of dry soybean seeds to water was 1:20 (w:w). The soybean slurry was then filtered through a Phillips filter screen and approximately 400 mL of soymilk was isolated. The soymilk was boiled for 10 min and then served at 70 °C in glass cup for sensory evaluation. This temperature was selected according to the drinking habit for soymilk in China. Generally, Chinese people prefer hot soymilk to cold one, which is similar to the drinking habits for coffee or tea.

2.3. Sensory attributes evaluation of soymilk

For the sensory evaluation, the soymilk samples prepared from six soybean genotypes were tested in duplicate at each panel session and the cultivar ZH13 was used as a control; *cv.* ZH13 is a leading soybean cultivar in the Yellow and Huai valley region of China. This cultivar exhibited a high content of protein and a relatively good soymilk quality score in a preliminary sensory test. The procedure for the sensory evaluation is shown in Fig. S2. The sensory evaluation was performed by at least eight trained panelists (25–30 years of age) from the Institute of Crop Science, Chinese Academy of Agricultural Sciences. Each panelist received 6 h of training sessions and practice in soymilk evaluation. During the training, panelists evaluated and discussed soymilk sensory attributes by comparing to *cv.* ZH13. Specific attributes, attribute definitions, and references were developed by the panelists (data not shown). Panelists compared six parameters—including colour and appearance, aroma, sweetness, thickness in the mouth, smoothness in the mouth, and overall acceptability—and assigned a score to each sample based on a 7-point hedonic scale (1–7) for soymilk flavour sensory evaluation: 1 = 'strongly disliked'; 2 = 'moderately disliked'; 3 = 'slightly disliked'; 4 = 'indifferent'; 5 = 'slightly liked'; 6 = 'moderately liked'; and 7 = 'strongly liked' (Robinson, Chambers, & Milliken, 2005). To adapt to a traditional taste style, the soymilk was kept at approximately 70 °C before sensory evaluation. The analysis of variance (ANOVA) indicated that the panel and panelists could consistently use the attributes to differentiate the soymilk samples.

For the soymilk flavour evaluation, the basic panel procedures followed the previous method (Chambers, Jenkins, & McGuire, 2006). The panel tasted one sample at a time. The flavour and mouth feel attributes were recorded 60 s after swallowing. The panel openly discussed each soymilk sample to reach a consensus concerning the flavour and mouth feel properties.

2.4. Determination of protein and oil content

The protein and oil content could be estimated by near-infrared spectroscopy (Hymowitz, Dudley, Collins, & Brown, 1974). In this study, 50 g of soybean seeds for each sample were analysed by transform near-infrared absorption spectroscopy (Bruker Fourier, Germany). The spectrum value of each sample represented the