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Quality predictive models for whole flour of immature wheat during storage and consumer acceptance on its baked product

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A B S T R A C T

The objectives of this study were to investigate quality changes in whole flour of immature wheat (WFIW) stored during 24 wk at different temperatures (0, 25, 35 or 45 °C) and to develop Arrhenius models to predict its quality. Color coordinates a* and b*, α-amylase activity, falling number (FN), setback, and final viscosity as quality attributes of WFIW during storage were measured every 4 wk for 24 wk and the changes were kinetically modeled using the Arrhenius equation. The activation energy (*Ea*) of quality attributes was in the range of 23,000–70,000 kJ/mol and that for FN was the highest, which was 70,000 kJ/mol. Additionally, volatile compounds in WFIW and consumer acceptance of cookies baked with WFIW as an end-product were measured. Among the volatile compounds, the propan-2-one and hexanal dramatically increased in WFIW stored at relative high temperature (35 or 45 °C) for prolonged period. Consumer acceptance of cookies showed that consumers prefer cookies made with WFIW stored relatively low temperature (0–25 °C).

1. Introduction

Wheat (*Triticum aestivum* L.) is one of the major grains consumed as flour and an essential human nutritional source of carbohydrates and proteins (Gonzalez-Torralba, Arazuri, Jaren, & Arregui, 2013). Recently, a few studies reported utilization and advantages of immature wheat flour as food ingredient (Levent & Bilgiçli, 2016; Pepe, Ventorino, Cavella, Fagnano, & Brugno, 2013; Yang et al., 2012). Immature wheat flour has been used for cereal based products such as pasta (Casiraghi et al., 2013) and bread (Levent & Bilgiçli, 2016; Pepe et al., 2013). Previous studies reported that immature wheat grain contained more fiber, essential amino acids, minerals, and fructo-oligosaccharides than mature wheat (Levent & Bilgiçli, 2016; Pepe et al., 2013; Yang et al., 2012). Additionally, immature wheat kernels or its bran contain more phenolic compounds, antioxidant capacities, and antiproliferative activities than mature wheat (Kim & Kim, 2016; Kim, Yoon, & Kim, 2016). Although previous studies reported beneficial health effects of immature wheat and nutritional values of products made with immature wheat flour, no information is available on quality changes of whole flour of immature wheat (WFIW) during storage. Generally, determining the properties of novel food materials and any changes during storage is very important for the food industry, as it provides information regarding the amount of time for which a product retains an appropriate level of quality (Ganje et al., 2016). Furthermore, whole wheat flour containing germ and bran has a relatively high enzyme activity compared to refined wheat flour, suggesting that whole wheat flour may have a shorter storage period than refined wheat flour (Every, Simmons, & Ross, 2006). WFIW production is limited due to lack of information about shelf-life expectations, even though it is available as alternative flour with health benefits.

Several physical and chemical changes take place in flour during storage (Zarzycki & Sobota, 2015). With prolonged storage, flour may reach an undesirable state and those changes might affect flour quality such as color, lipid oxidation, α-amylase activity, and pasting properties. Eventually, flour stored for extended long periods could cause adverse effects on processing and end-product quality (Fierens, Helsmoortel, Joye, Courtin, & Delcour, 2015; Wang & Flores, 1999). During storage, color coordinate b* plays a major role in the evaluation of flour quality as consumers tend to be reluctant to purchase or use flour with high yellowness (Li et al., 2013; Paraginski, Vanier, Berrios, de Oliveira, & Elias, 2014). Falling number (FN), which is related to α-amylase activity, has also

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been used as a quality indicator of flour (Zarzycki & Sobota, 2015). Additionally, setback and final viscosity, among pasting properties, are related to retrogradation and may affect the quality of the end product (Fierens et al., 2015). Therefore, FN, setback, and final viscosity in WFIW were used as critical attributes to determine the quality of WFIW during storage in this study. Also, degradation such as lipid oxidation during flour storage was reported to be the predominant cause of loss of flour functionality (Doblado-Maldonado, Pike, Sweley, & Rose, 2012). The lipid oxidation occurred during prolonged storage of flour, consequently generating many volatile compounds (Doblado-Maldonado et al., 2012; Robards, Kerr, & Patsalides, 1988). According to Xu, Yu, Liu, and Zhang (2016), electronic noses can be used for rapid discrimination of samples by detecting volatile compounds from lipid oxidation.

The Arrhenius equation is the most common model used to evaluate expected quality losses of food products during storage base on the precise relationship between temperature and reaction rate constant (Ganje et al., 2016). Quality changes estimated using the Arrhenius equation have been reported for various foods such as tomato paste (Ganje et al., 2016), beef (Olivera, Bambicha, Laporte, Cardenas, & Mestorino, 2013), and einkorn and wheat flour (Hidalgo & Brandolini, 2008). However, there is no information available on use of the Arrhenius equation to determine quality changes of WFIW during storage.

Previously, Kim and Kim (2016) reported more antioxidant capacity than mature wheat. The results of preliminary experiments for this study showed that antioxidant capacity of WFIW did not change during storage (Supplementary Fig. 1), implying that storage time of WFIW did not affect its beneficial health effects. Thus, phenolic compounds, antioxidant capacities and antiproliferative activities were not included as quality factors to predict shelf-life of WFIW. The purpose of this study was to predict quality changes of WIWF during storage using the Arrhenius model. Color coordinates a* and b*, α-amylase activity, FN, setback, and final viscosity were used as quality indices to predict flour quality during storage. In addition, volatile compounds were analyzed to expect lipid oxidation during storages of WFIW using an electronic nose. Consumer acceptance of cookies baked with WFIW was studied to evaluate acceptability of end-product made with WFIW stored at different storage time and temperatures.

2. Materials and methods

2.1. Flour samples and storage conditions

The immature wheat used in this study was a hard wheat cultivar (*T. aestivum* L. cv. Keumkang) grown in Iksan (Jeollabuk-Do, Korea, geographic coordinates: 35°56′N, 126°53′E) and harvested 35 d after the heading date in 2014. The moisture content of immature wheat was 30 g/100 g, when harvested. After harvesting, the immature wheat was dried to a moisture content of 9 g/100 g using a heated air drier (HK-D0100F, Hankuk General Equipment Plant, Hwaseong-si, Korea). Dried immature wheat was milled into whole wheat flour using an air classifying mill (SM500, Shin Myung High Tech., Siheung-si, Korea) equipped with an 80-mesh sifter. After milling, proximate compositions of the whole flour of immature wheat (WFIW) was 10 g/100 g crude protein, 1.8 g/100 g crude lipid, 1.4 g/100 g ash, and 8.7 g/100 g moisture, respectively.

WFIW was packaged in opaque polyethylene bags in 1 kg units and the packaged WFIW were stored at 0, 25, 35, and 45 °C for up to 24 wk. During storage, temperature was recorded using a thermo recorder (TR-72wf, T&D Corporation, Nagano, Japan). Color coordinates (L*, a*, and b*), α-amylase activity, FN, pasting properties, and volatile compounds analysis of WFIW were measured with 4 wk interval. WFIW stored for 12 and 24 wk were used for consumer acceptance testing for cookies. The WFIW stored at −20 °C after milling was used as control for all experiments.

2.2. Quality attributes of WFIW during storage

The color of WFIW was measured using a colorimeter (CR-300, Minolta, Tokyo, Japan). Black and white calibration references were used to standardize the instrument before analysis. The parameters recorded were L* (lightness), a* (−a* = green, +a* = red), and b* values (−b* = blue, +b* = yellow).

Alpha-amylase activity was determined according to AACC method 22–02.01 (AACC, 2000). Enzyme activities were expressed in α-amylase units (AU) per 100 g dry weight basis (dwb) of WFIW. One unit is defined as the amount of enzyme increased at $A_{405\text{nm}}$.

FN was determined according to AACC method 56–81B (AACC, 2000) by using a Falling Number 1500 (Perten Instruments, Stockholm, Sweden).

Pasting properties were determined by using a Rapid Visco Analyzer (RVA, Super 4, Newport Scientific Inc., Sydney, Australia) according to AACC method 76-21 (AACC, 2000). The peak viscosity, trough, break down, final viscosity, setback, peak time, and pasting temperature were recorded. The viscosity values are reported in mPa.s.

2.3. Kinetic modeling

To estimate quality loss during storage of WFIW, a kinetic model was developed by using the Arrhenius equation. Generally, a kinetic model to predict quality changes during storage of foods or ingredients can be expressed as:

$$-\frac{dQ}{dt} = \mathrm{k}Q^{n} \tag{1}$$

where Q is the measured quality attribute (e.g., color, FN, α-amylase, pasting properties), t is time (wk), and k is the reaction rate constant estimated by the slope of the linearized plot of Q vs. t for the zero order. Usually, zero-order ($n = 0$) or first-order ($n = 1$) kinetics models are used for overall quality of foods (Singh, 2000). Considering the R^2 of the zero-order and first-order models, the zero-order kinetics model was better than the first-order kinetics model in this study. The Arrhenius equation (2) was used to evaluate the temperature dependence of each k value:

$$\mathrm{k} = k_0 \exp\left[-\frac{Ea}{RT}\right] \tag{2}$$

where Ea, R, T and k_0 are activation energy of each reaction (kJ/mol), the universal gas constant (8.314 J/mol K), absolute temperature, and pre-exponential factor, respectively. Substituting Eq. (2) into Eq. (1) yields:

$$\frac{dQ}{dt} = k_0 \exp\left[-\frac{Ea}{RT}\right]Q^{n} \tag{3}$$

Integrating Eq. (3) results in

$$\int_{Q_0}^{Q(t)} \frac{dQ}{Q^{n}} = \int_{0}^{t} k_0 \exp\left[-\frac{Ea}{RT}\right] dt \tag{4}$$

A zero-order kinetic equation is developed when substituting $n = 0$ into Eq. (4):