Journal of Cereal Science 46 (2007) 11–21

Journal of CEREAL SCIENCE

www.elsevier.com/locate/yjcrs

Fourier modelling, analysis and interpretation of high-resolution mixograph data

A.P. Verbyla[a,*], C. Saint-Pierre[b], C.J. Peterson[b], A.S. Ross[b], R. Appels[c,d]

[a] School of Agriculture, Food and Wine, The University of Adelaide, Private Mail Bag 1, Glen Osmond, SA 5064, Australia
[b] Department of Crop and Soil Science, Oregon State University, Corvallis, Oregon 97331, USA
[c] Molecular Plant Breeding CRC, Murdoch University, Perth, WA 6250, Australia
[d] Department of Agriculture and Food, Murdoch University, Perth, WA 6250, Australia

Received 29 June 2006; received in revised form 24 October 2006; accepted 31 October 2006

Abstract

High resolution mixograph data (HRMD) has the potential to provide improved information on dough rheology. A designed experiment involving nine cultivars grown under two levels of nitrogen fertilization and three levels of irrigation motivated the method of analysis that is based on time-varying Fourier terms. The procedure involves a preliminary time series analysis in the frequency domain based on the periodogram, to determine the main cyclic patterns in the data, followed by modelling of the cyclic patterns found. The estimates of the peak value in dough development and the associated time based on the resulting major cyclic frequency are shown to correlate highly with the existing method of analysis using Mixsmart software. The measure of bandwidth is based on the maximum of the time-varying amplitude of the sinusoidal term corresponding to the major frequency over time. The trace of this amplitude provides a clear single maximum, improves the ability to separate varieties in terms of bandwidth, and has the potential for characterizing dough extension across the full mixing process.

Keywords: Dough mixing; Fourier analysis; Mixograph; Rheology

1. Introduction

The proteins of the wheat gluten complex are largely responsible for determining the end-use properties of dough produced from wheat flour (reviewed in Gras et al., 2001). Key features of the dough produced from wheat flour include its water absorption, strength (R_{max}) and extensibility, and it has been argued that a single trace from a mixograph analysis can provide a good guide to some of these features (Békés et al., 2001). Detailed analysis and interpretation of high resolution mixograph data (HRMD) for wheat flour is now possible with the availability of electronic outputs from the mixograph (Brabec et al., 2002; see also Gras et al., 2001) and these outputs form the basis of the present manuscript.

The mixograph pin-based mixing action has been well characterized (Gras et al., 2000; Brabec et al., 2002). The four moving pins (two pairs) trace epitrochoidal paths (Buchholz, 1990; Steele et al., 1990) and the torque applied to the dough by the pins provides the energy input to develop the dough. Although 12 pins are involved in the mixing action (three fixed and four moving), pairs of mixing pins straddle or hurdle the stationary bowl pins (Brabec et al., 2002), and hence define six sub-cycles within a given mixing cycle. Greater torque is developed during the hurdling process because both pins travel at maximum velocities and distance from the centre (Brabec et al., 2002). The Fourier, and subsequent, analyses carried out in the present manuscript on mixograph data are based on the concept that signals such as those from a mixograph can be

Abbrevations: AACC, American Association of Cereal Chemists; BLUP, best linear unbiased predictor; HRMD, high-resolution mixograph data; HWW, hard winter wheat; N, nitrogen; rpm, revolutions per minute; REML, residual maximum likelihood; SWW, soft winter wheat; USDA-ARS, United States Department of Agriculture-Agricultural Research Service.

*Corresponding author. Tel.: +61 8 8303 8769; fax: +61 8 8303 8763.
E-mail address: ari.verbyla@adelaide.edu.au (A.P. Verbyla).

0733-5210/$ - see front matter
doi:10.1016/j.jcs.2006.10.008

approximated by a sum of sinusoidal curves, each at a different frequency and amplitude. The aim of the analysis was to extract the properties of the flour being studied at each of the sub-cycles within the mixing action of the mixograph as defined by Brabec et al. (2002), and thus form a basis for determining if components of flour processing such as dough strength (e.g. maximum resistance to extension ($R_{\max}$)) and extensibility can be implied from these measurements (Gras et al., 2001). Békés et al. (2001) for example defined a component they referred to as *M*-extensibility, obtained from an empirical analysis of mixograph data.

The cyclic nature of the mixing process of the mixograph suggests that the factors determining rheological properties of flour may be defined within the cyclic patterns and their extent. Anderssen et al. (1998) showed that the number of cycles or revolutions to peak dough development was constant over different revolutions per minute (rpm) and that the time to peak resistance depends on the rpm. The bandwidth, the resistance of the dough to shearing in mixing, is a key characteristic in assessing the strength of dough. Gras et al. (2000) indicated that HRMD can be viewed as providing a large number of extension tests composed of stretching and shearing of the developing dough and that the variation in bandwidth during mixing is indicative of the role played by the added water. Thus the examination of the bandwidth during the mixing process is a key aim of the approach presented.

We present an approach for the analysis of HRMD based on exploratory time series analysis in the frequency domain, together with flexible modelling of amplitude (and hence bandwidth during mixing) and phase of the resulting representation. For certain characteristics of the HRMD, the analysis is closely connected with properties of the mixing curve extracted using the Mixsmart software when applied to an experiment involving nine cultivars and a 2×3 factorial treatment structure. A bandwidth measure is proposed and is given by the maximum of the amplitude of the major cyclic frequency in the mixograph. The amplitude is usually a smooth curve over the mixing process, has a single maximum, and is largely repeatable. Thus the bandwidth during mixing and the maximum bandwidth are provided by the analysis. When compared to the Mixsmart analysis, an important difference of the new approach is the improvement in the discrimination between cultivars (and treatments) when using the new bandwidth measure, and the ability to provide a bandwidth measure across the entire mixing process.

2. Experimental

2.1. Mixing experiments

Seven hard white winter (HWW) and two soft white winter (SWW) wheat cultivars were grown in 2003–2004 at Oregon State University, U.S. (Saint-Pierre, 2006). Plots were line-source irrigated during grain-fill to replace 30–50% (treatment I1), 50–80% (treatment I2) and 80–100% (treatment I3) of measured evapo-transpiration. Plots also received two levels of soil nitrogen (coded as low and high N). The low N level treatment consisted of a single fertilization of 170 kg N/ha at late tillering. For the high N level, a second application of 170 kg N/ha was done at early stem extension.

The nine selected varieties were highly variable for glutenin composition. 'Stephens' is an Oregon SWW variety. 'Eltan' is a late maturing soft white released by Washington State University, generally considered to have relatively strong dough characteristics. 'NW97S277' is an USDA-ARS and University of Nebraska HWW variety ('Antelope' sib). 'IDO591' is a University of Idaho HWW experimental line with end-use quality suited to both domestic bread use and Asian noodle products. 'OR85051319', 'OR941048', 'OR942496', 'OR943576', and 'OR953475' are Oregon State University HWW experimental lines with different glutenin compositions.

Grain and flour protein content was measured with a LECO nitrogen/protein determinator. Grain was milled to flour using a Brabender Quadrumat Senior test Mill (C.W. Brabender Instruments, Hackensack NJ, USA) after tempering to 14% and 15%, respectively for soft- and hard-grained wheats. Physical dough properties were measured using a 10 g mixograph (National Manufacturing Division of TMCO, Lincoln NE, USA). Two samples of 10 g of each of the flours were evaluated on the mixograph using AACC 54-40A with the exception that a fixed water addition of 6.0 mL was used for all samples. Mixograph curves were analysed using Mixsmart software (National Manufacturing Division of TMCO, Lincoln NE, USA). A good description of the output from the Mixsmart software is presented by Martinant et al. (1998).

At a standard mixograph-mixing rate of 88 rpm, 22 mixing cycles occur per minute so that one mixing cycle takes 2.72 s (Brabec et al., 2002). Although 12 pins are involved in the mixing action (three fixed and four moving), pairs of mixing pins straddle or hurdle the stationary bowl pins (Brabec et al., 2002), and hence define six sub-cycles within a given mixing cycle. Each sub-cycle contains movements where two moving pins either hurdle or straddle a stationary pin. One sub-cycle occurs every 0.453 s. The standard 10 g mixograph (National Manufacturing) was used to collect mixing data at 10 points per second for an 8 min period (that is a total of 4800 points) and the electronic data collected into a simple Excel format for further analysis.

The data to be analysed consists of a sample from each of two field replicates of each of the wheat varieties under the irrigation by nitrogen factorial treatment structure. Thus initially 108 mixograph runs were planned, but two runs were aborted and hence 106 mixographs make up the full data to be investigated.

A graphical representation of one mixograph run of flour from the wheat cultivar Eltan under low fertilization and the highest level of irrigation is given in Fig. 1. This figure provides an overall view of the complex mixing process.