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Original papers

Development of artificial intelligence based systems for prediction of hydration characteristics of wheat

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A B S T R A C T

Hydration characteristics (moisture content, moisture ratio and hydration rate) of wheat kernel during soaking process were studied and simulated. Hydration procedure was performed at five different experimental water temperatures (30, 40, 50, 60 and 70 (°C)) with respect to hydration time changes. Hydration characteristics of samples were modeled using one of the most popular simulation frameworks of artificial intelligence, adaptive neuro-fuzzy inference system (ANFIS). A comparison was also made between results of the best developed ANFIS model and those of the another well-known artificial intelligence technique, artificial neural network (ANN). The hydration temperature and time were used as input parameters and moisture content, moisture ratio and hydration rate were taken as output parameters of the intelligent modeling frameworks. To attain the best model with the highest predictive ability, developed models were compared based on statistical parameters of coefficient of determination, root mean square error and mean relative deviation modulus. According to the results, although the best framework of both ANFIS and ANN were able to accurately predict hydration characteristics, the best ANN simulation framework with a simple structure (2–4–3) was easier to use than the ANFIS with three different structures. ANN surface plots also illustrated that increasing the hydration temperature and time increased moisture content and decreased moisture ratio. Moreover, ANN modeling results indicated that the hydration rate increased in the initial and decreased in the middle and final phase of hydration procedure.

1. Introduction

Hydration is widely used as a pre-treatment for legumes and cereals before some processing operations such as extraction, cooking, germination, tempering and wet milling. It is necessary to know water absorption behavior in legumes and cereals during hydration because it affects following processing operations and the quality of the final product (Turhan et al., 2002).

In this context, there are a large number of researches reporting that many authors have investigated the hydration characteristics of different cereals and legumes at various conditions. Some of these attempts can be cited for rice (Kashaninejad et al., 2007), bean (Piergiovanni, 2011), corn kernels (Marques et al., 2014), lentil (Oroian, 2015) and soybean (Fracasso et al., 2015).

According to the literature, it can be inferred that the better understanding of the hydration kinetics of food products is achieved by modeling the hydration procedure accurately. Realizing the importance of this point resulted in development of several mathematical models to describe the hydration characteristics.

Peleg model is one of the well-known models frequently used by researchers to predict moisture content and hydration rate of agricultural products in hydration procedure (Maharaj and Sankat, 2000; Shittu et al., 2004; Cunningham et al., 2007; Kashiri et al., 2010; Shafaei et al., 2016). Also, Weibull model has commonly been applied in previous studies to predict moisture ratio of agricultural products (Marabi et al., 2003; Garcia-Pascual et al., 2006; Goula and Adamopoulos, 2009; Diaz-Ramirez et al., 2013; Rafiq et al., 2015). Other mathematical models for prediction of hydration characteristics of agricultural products can be found in the literature (Ibarz et al., 2004; Saguy et al., 2005; Wood and Harden, 2006; Vega-Galvez et al., 2009; Shafaei and Masoumi, 2014a, b, c; Oli et al., 2014; Ibarz and Augusto, 2015).

The hydration modeling has been performed in respect of hydration time using mathematical models for certain hydration temperature. The fitted models predicted the moisture content or moisture ratio based on one variable (hydration time). Coefficients of the models also changed with hydration temperature change. However, a comprehensive multiple variable model should be used

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Nomenclature

S	sphericity (%)
D_g	GMD (mm)
T	thickness (mm)
MC	moisture content (d. b. %)
MC_f	saturated moisture content (d. b. %)
W_f	mass of wet wheat kernel (g)
$MC_{(t+\Delta t)}$	moisture content at time (t + Δt) (d. b. %)
$MC_{(t)}$	moisture content at time (t) (d. b. %)
W_i	initial mass of wheat kernel (g)
MC_i	initial moisture content (d. b.%)
S_a	surface area (mm^2)
L	length (mm)
W	width (mm)
E_a	average of experimental data
P_i	ith predicted data
E_i	ith experimental data
Δt	hydration time (min)
HR	hydration rate (d. b. %/min)
n	number of used data
MR	moisture ratio

Abbreviations

3D	three dimensions
AAVRE	average of absolute values of residual errors
ANFIS	adaptive neuro-fuzzy inference system
ANN	artificial neural network
ANOVA	analysis of variance
DMRT	Duncan's multiple range test
GMD	geometric mean diameter
MLP	multi-layer perceptron
MRDM	mean relative deviation modulus
RMSE	root mean square error

for accurate prediction of hydration characteristics (moisture content, moisture ratio and hydration rate) of agricultural products during soaking based on multiple inputs (hydration time and temperature).

Development of intelligent models for prediction of multiple variable phenomena has resulted in general use of them in scientific and engineering practices. Unlike previously common modeling techniques, such as regression equations, artificial intelligence modeling techniques are applied to predict the target variable using more than one input and output. Moreover, such models are capable of determining nonlinear relationships existing between output and input variables. ANNs are data simulation frameworks based on the structure of the biological neural system. These intelligent models are mostly useful where old techniques fail to work correctly. ANFIS is also a new simulator tool used to increase the prediction efficiency of nonlinear relationships according to the theory of training algorithm and expert knowledge in a controlled environment.

Artificial intelligence modeling techniques have already been applied to simulate different processes. The literature includes studies which present the use of ANN to predict the nonlinear relationships in agricultural engineering applications (Adhikari and Jindal, 2000; Diamantopoulou, 2005; Lertworasirikul and Saetan, 2010; Torrecilla et al., 2016). In addition, a careful review of the literature shows the capability of ANFIS simulation environment in proper estimation of desired agricultural parameters (Brown-Brandl et al., 2005; Ghoush et al., 2008; Amiryousefi et al., 2011; Sefeedpari et al., 2014; Shafaei et al., 2015).

Some researchers have studied the hydration characteristics of wheat kernel from different points of view. Thus, several hydration conditions and modeling techniques were examined to optimize the performance of the related processing equipment (Bloome et al., 1982; Kang and Delwiche, 1999, 2000; Maskan, 2001, 2002; Tagawa et al., 2003; Muramatsu et al., 2006; Kashaninejad and Kashiri, 2008; Kashaninejad et al., 2009; Vengaiah et al., 2012; Xingjun and Ping, 2016). In a research, Kashaninejad et al. (2009) found that the ANN modeling based on MLP network was better than the generalized mathematical Page model for prediction of moisture ratio. Subsequently, Kashiri et al. (2012) confirmed this result for modeling of sorghum hydration.

Generally, published literature is lacking a comprehensive study of hydration characteristics of wheat kernel and intelligent modeling of its hydration behavior using ANFIS model. Therefore, this study was carried out to develop an ANFIS intelligent model for directly prediction of moisture content, moisture ratio and hydration rate of wheat kernel during soaking based on simultaneous change of hydration temperature and time. The results were also compared with those obtained from ANN intelligent model. Moreover, the significance of the effect of hydration temperature and time on hydration behavior of wheat kernel was determined by means of statistical analysis methods.

2. Materials and methods

2.1. Sample preparation

Shiroudi variety of wheat (*Triticum* spp.) was provided by Seed and Plant Breeding Unit, Agricultural Research Center of Fars province, Iran. The variety was selected, because it is one of the most commonly cultivated varieties in south region of country. Prior to hydration experiments, the samples were manually cleaned using napkin in order to eliminate foreign materials such as gravel, dust and broken kernels.

The initial moisture content of cleaned samples was determined according to ASABE standard method for wheat seed (ASABE, 2006). Ten-gram samples were dried in a convection oven at 130 ± 1 (°C) for 19 h. To avoid measurement error, the experiments were performed three times and mean value was used. The initial moisture content of wheat kernel was found to be 9.407% (d. b.).

The samples were packed in separate polyethylene bags and stored in a refrigerator at 5 ± 0.5 (°C) for ten days. The needed quantity of samples was placed at ambient condition to warm up to room temperature, approximately two hours before starting each test (Abalone et al., 2004).

2.2. Physical properties

To determine some physical properties of the samples, 100 kernels were randomly picked out. Their three principal dimensions (length, width and thickness) were then measured using a digital caliper (manufacture: Neiko, model: 01409A, made in USA) reading to an accuracy of 0.01 (mm). The samples were weighed with a precision electronic balance (manufacture: A&D company, model: GF-600, Japan) with 0.001 (g) accuracy. Furthermore, some shape parameters of the samples (GMD, sphericity and surface area) were calculated using the following equations (Mohsenin, 1986):