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Development of a rheological prediction model for food suspensions and emulsions

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ABSTRACT

The rheological behavior of 34 commercial food dispersions was investigated and modeled with the Herschel–Bulkley model. Artificial neuronal networks (ANNs) were trained to predict the rheological parameters yield stress τ_0, consistency coefficient K and flow behavior index n in dependency of the composition of fats, carbohydrates, proteins and water. ANNs with 3 hidden layers and 2 neurons per layer showed good to very good results for all Herschel–Bulkley parameters.

1. Introduction

Food dispersions namely e.g., condiment sauces, dressings, and mayonnaises consist of a mixture of lipids, proteins, carbohydrates and water and are produced mostly in industrial scale. Reliable dimensioning and optimization of production processes requires comprehensive knowledge of physical properties of these products. The investigation of these characteristics is time consuming and requires laboratory resources.

For this reason prediction models of product properties on the basis of product composition can ease and quicken product, process and equipment design (Halder et al., 2011). However prediction models on the basis of composition of proteins, carbohydrates, fats, and water are only available for thermal but not for rheological characteristics (Choi and Yoo, 2004; Nesvadba, 2005, 2008). The prediction of rheological properties is challenging since composition and underlying structures of these products are complex.

The objective of this work was the development of a prediction model for rheological properties of an unknown product based on the composition of carbohydrates, proteins, fats and water by utilization of artificial neuronal networks (ANNs).

2. Background

2.1. Composition of food dispersions

In general typical food dispersions have an aqueous continuous phase, which characterizes the mechanical properties. The addition of the basic constituents fats, carbohydrates and proteins results in the characteristic properties. The composition and the concentration of these constituents significantly influences the rheological properties (Genovese et al., 2007; Mandala et al., 2004). These systems can be differentiated into emulsion and suspension character depending on the state of aggregation of the discontinuous phase. Emulsions are defined as a fine dispersion of one liquid throughout a second, largely immiscible liquid (Grace, 2004; Robins et al., 2002). Suspensions are defined as fluids, which consist of a solid discontinuous phase and a continuous aqueous phase (Tscheuschner, 1993).

The components can be distinguished into a hydrophilic part which is represented by carbohydrates, proteins and hydrophobic fats. Some of the hydrophilic substances exhibit amphiphilic behavior, which mark a key parameter for sauces with an increased fat content (Sheldrake, 2003). The mechanical properties can be affected by the amount, distribution and stabilization of these ingredients.

Fat or oil respectively within the continuous water phase of a emulsion in increasing concentration results in rising viscosity and implicates an appropriate processing step for the dispersion of the oil in water as well as the application of an emulsifier to create a stable emulsion (Sheldrake, 2003; Franco et al., 1997; Abu-Jdayil, 2003). The need for fat reduced and low-fat products leads to the substitution of fat by non-fat ingredients. The substitutes have to mimetic the textural and mechanical behavior of fat, which is achieved usually by addition of a combination of carbohydrate or protein based hydrocolloids (Phillips and Williams, 2000; Peressini et al., 1998; Liu et al., 2007; Wendin and Hall, 2001).

Carbohydrates can be distinguished into non-thickening and thickening. Latter consist of oligo- and polysaccharides and influence the rheological properties to a great extent even by addition

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of small amounts. These substances modify the structural and textural properties by bulking and formation of networks, which lead to partial immobilization of water and thus an increase of viscosity (Sheldrake, 2003). Besides their ability to increase the viscosity of the continuous water phase some polysaccharides in addition show emulsifying capacity (Dickinson, 2003).

Proteins usually function as emulsifiers, which allow the stabilization of oil droplets. In addition proteins derived from milk and eggs like whey protein, caseinates, and vegetable proteins have the ability to bind and form networks and thus modify the viscosity of a product. The emulsifying capabilities of proteins are caused by hydrophilic and hydrophobic groups of the macromolecules, leading to surface activity as well as further steric stabilization (Martinez et al., 2007).

2.2. Artificial neuronal networks (ANNs)

Artificial neural networks are mathematical non-linear statistical systems, which allow modeling by emulating the functional aspects of biological neural networks and consist of artificial neurons that are connected with each other for data exchange. ANNs can have several weighted inputs and outputs and each neuron can perform simple mathematical functions with the inputted data (Marini, 2009).

The weights and thresholds are being set during the teaching of the net. The net can adjust itself during the teaching to the training data. As a result patterns the input data can be learned by the network. These capabilities are used in various fields of research. In food science ANNs were used for modeling of technological processes e.g., reaction kinetics (Geeraerd et al., 1998a,b) as well as for the prediction of physical properties e.g., thermal conductivity (Sablani and Rahman, 2003).

3. Material and methods

The prediction model was developed observation based, for which reason the rheological properties of different products were investigated. The resulting data was used as a base for the training of the ANNs.

3.1. Products of investigation

For this investigation 34 different commercial food emulsions and suspensions were purchased at a local retail market and stored at 5 °C. The list of investigated products and their corresponding composition of proteins, carbohydrates, fats and water can be seen in Table 1.

The composition information was taken from nutrition labeling of the manufacturer, which is based on the Directive 90/496/EEC on nutrition labeling for foodstuffs, Article 6. The declared values can be based on the manufacturer's analysis of the food, a calculation from the known or actual average values of the ingredients used or a calculation from generally established and accepted data (Council Directive 1990).

3.2. Rheological measurements

The rheological measurements of 34 commercial food emulsions and suspensions were performed with a Thermo Haake R-S 300 rheometer in combination with a Haake universal temperature controller (UTC). In order to avoid slippage a parallel serrated plate/plate measuring device PP35 PR with a diameter of 35 mm was selected (Batista et al., 2006; Dolz et al., 2007; Riscardo et al., 2004; Quintana et al., 2002). Prior to each measurement the samples were subjected to a pre-shear step for 120 s at a shear

Table 1
Products of investigation and their corresponding composition.

No	Sauce	Fat (%)	Protein (%)	Carbohydrate (%)	Water and ash (%)	Hydro-colloids
1	Tomato Ketchup 1	0	0	25	75	1
2	Brown sauce	0.1	0.9	24.3	74.7	1
3	Barbecue sauce 1	0.1	0.5	46.8	52.6	1, 3
4	Chili sauce1	0.1	1	24.2	74.7	1, 2
5	Tomato ketchup light 1	0.1	1.4	11.8	86.7	None
6	Tomato ketchup light 2	0.1	0.9	10	89	5, 6, 7
7	Tomato ketchup 2	0.1	0.9	24.1	74.9	None
8	HP sauce	0.2	1.1	27.1	71.6	1
9	Cooking sauce 1	1.2	0.6	7.3	90.9	1, 3, 4
10	Salad dressing	1.4	0.2	2	96.4	1, 3, 4
11	Chili sauce 2	1.6	0.2	31.5	66.7	1, 3
12	Chocolate sauce	1.9	2.6	59	36.5	7
13	Barbecue sauce2	1.9	1	18.5	78.6	1
14	Salad creme 1	3	0.6	11	85.4	1, 3
15	Vanilla sauce 1	3.1	2.8	17.1	77	1, 7
16	Vanilla sauce 2	3.3	3.3	18.7	74.7	1, 7
17	Vanilla sauce 3	6	2.7	18	73.3	1, 7
18	Caramel sauce	6.5	3	58.3	32.2	None
19	Joghurt dressing	10.7	1.5	9.4	78.4	1, 3, 4, 8
20	Vanilla sauce 4	10.9	5.5	19.6	64	5, 7
21	Cooking sauce 2	12.3	1.1	4.5	82.1	1, 3
22	Salad creme 2	15.4	1.4	12.9	70.3	1, 3
23	Salad creme 3	22.5	0.3	12.5	64.7	1, 2, 3, 4
24	Cocktail sauce	22.8	1.9	14.5	60.8	3, 4
25	French fry sauce	25.5	0.5	12.5	61.5	1, 2, 3, 4
26	Salad creme 4	26.2	0.8	26.6	46.4	1, 2, 3
27	Salad creme 5	26.8	1.4	20	51.8	1, 3, 4
28	Cocktail sauce	27.2	0.7	10.8	61.3	1
29	Salad creme (3) 6	30.8	1.1	11.7	56.4	1, 4, 5
30	Seafood sauce	43.3	1.2	23.5	32	2, 3, 4
31	Salad mayonnaises 1	51	0.8	7.4	40.8	1, 4
32	Salad mayonnaises 2	51.1	0.5	11.3	37.1	1, 2, 4, 5
33	Salad mayonnaises 3	54.1	0.4	8.3	37.2	1
34	Mayonnaises	79.1	1.3	0	19.6	None

1, modified starch; 2, native starch; 3, xanthan gum; 4, guar gum; 5, locust bean gum; 6, alginate; 7, carrageenan; 8, pectine.