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Optimization of process parameters for continuous *kheer*-making machine

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ABSTRACT

If rice is cooked in milk, starch–milk reaction results into a thick product, which is very popular in India known as *kheer*. Conventionally, *kheer* is prepared by cooking rice in milk in an open pan over low fire followed by addition of sugar toward the end. The present investigation aims to optimize the process parameters (operating pressure and cooking time) for designing the pressurized cooking section of a continuous *kheer*-making machine. Sensory trials of *kheer* prepared conventionally and using pressurized methods were carried out and the data was analyzed using Fuzzy Logic. Sensory results of open-pan samples indicated that there is a small range of Whiteness Index (*WI*) and Hardness (*H*) values that is desirable in *kheer*. An Artificial Neural Network-Genetic Algorithm (ANN-GA) model was developed to further optimize the operating parameters to result in a product that would have the desired color and texture observed in *kheer* prepared conventionally. The developed ANN-GA model was successful in providing with input conditions leading to desired *WI* and *H* values. Finally, from the set of optimal input conditions, operating pressure of 0.27 MPa and cooking time of 7.5 min was chosen for designing the pressurized cooking section of the continuous *kheer*-making machine.

1. Introduction

The hydro-thermal processing of rice has become one of the most widespread food industries of the world since it constitutes a major part of the global nutritional need for carbohydrates (Bello, Tolaba, & Suarez, 2007; Bhattacharya, 1990; van den Doel et al., 2009). This includes cooking of rice at boiling conditions resulting in both water migration as well as starch–water reaction better known as gelatinization. If rice is cooked in milk, starch–milk reaction results into a thick product, which is very popular in India known as *kheer*. It is a form of a sweet dish commonly known as rice pudding in the United States and Europe.

Conventionally, *kheer* is prepared by concentrating milk with simultaneous cooking of rice in an open pan over low fire and addition of sugar toward the end of cooking. In many cases dry fruits can also be added to make it richer. This *kheer* has a creamish color as well as sweet, nutty and cooked flavor due to prolonged cooking (Jha, Patel, & Singh, 2002). *Kheer* is considered a nutritious dessert since it contains nutrients from both milk and rice (Kumar, Singh, Patil, & Patel, 2005). As *kheer* is prepared in an open pan i.e. at atmospheric pressure, it becomes a batch process, which limits its mechanized production. In order for its mechanization, it is necessary to reduce its cooking time, which is usually around 1 h in the conventional open-pan process. This can be made possible by increasing the operating pressure (beyond atmospheric pressures), which is the focus of the present study. Another key bottleneck in the commercial production of *kheer* is its poor shelf life. The average shelf-life of *kheer* is 2–3 days at 37 ± 1 °C and 10–15 days at 4 ± 1 °C. If thermal treatment is employed, shelf-life could be extended up-to 3–4 days at 37 ± 1 °C and upto 60–70 days at 4 ± 1 °C without addition of any preservatives (Aneja, Mathur, Chandan, & Banerjee, 2002; De, 1980). In a recent work, based on in-pouch thermal treatments using a rotary retort, Jha, Patel, Gopal, and Nagarajarao (2011) have reported an increase in the shelf life of up-to five months at 37 °C.

As of now, due to lack of organized manufacturing and marketing of *kheer*, there is no data on its annual production. Due to its wide acceptance in Indian households, *kheer* can contribute to a very great extent as far as traditional dairy products are concerned. Very few studies have been conducted on batch type *kheer* production processes focusing on its shelf-life and attempts to make the process mechanized and continuous are non-existent. Therefore, the need for development of suitable continuous

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processes and techniques for commercial manufacture of *kheer* is well appreciated, particularly for organized catering food services industry. A conceptual design of a continuous *kheer*-making machine is underway, consisting of a pressurized cooking section among other components, to reduce the time of cooking. The present investigation is undertaken with the prime objective to optimize the process parameters for the pressurized cooking section viz., operating pressure and cooking time.

1.1. Computer-based food process modeling and optimization

Experimental optimization of food processing operations is often time consuming due to large number of possible combinations between operating parameters. This often leads to enormous number of experiments. In most other cases, random variations in conditions and errors in measurements creep in to make experimental optimization all the more difficult. Hence, computer-based models that can accurately predict the effects of food processing are desired. Food processing is a complex interplay of several intrinsic biochemical properties and process variables, and hence warrants a strategic application of suitable modeling and optimization tools to obtain a feasible process ensuring optimum yield. Determination of optimal conditions for processing is the key to ideal industrial processing. Soft computing methodologies such as Artificial Neural Networks (ANN), Genetic Algorithms (GA), Fuzzy Logic (FL) have recently been found to offer novel solutions to improve control and modeling in food processing. These tools have received increased attention in several biological processing areas such as drying (Chen & Ramaswamy, 2002; Chen, Ramaswamy, & Alli, 2000), baking (Cho & Kim, 1998), fermentation (Teissier, Perret, Latrille, Barillere, & Corrieu, 1997), microbial growth modeling (Garcia-Gimeno, Hervas-Martinez, & de Siloniz, 2002) to name a few. The use of Fuzzy Logic (FL) to analyze sensory data has shown promise (Jaya & Das, 2003; Sinija & Mishra, 2008). In sensory evaluation using FL, linguistic data from subjective evaluation is converted to objective data to not only rank the different samples but to also identify the strong and weak quality attributes of the product (Das, 2005, pp. 383–452; Jaya & Das, 2003). Given such robustness and versatility of soft-computing tools, ANN, GA and FL have been employed in this study to optimize the process parameters for the pressurized cooking section of the continuous *kheer*-making machine and analyze the sensory acceptability of the product. In the present study, for modeling and optimization using hybrid ANN-GA, operating pressures and cooking times were chosen as input variables and Whiteness Index (*WI*) of *kheer* samples (a measure for color) and Hardness (*H*) value of cooked rice grains (a measure of texture/mouthfeel) were chosen as output variables. For sensory evaluation using FL, quality attributes such as Color, Mouthfeel, Aroma, Taste and Aftertaste of the samples prepared at elevated pressures were chosen. The specific objectives of the work that was carried out are as follows:

- Conducting sensory trials to determine acceptable ranges of *WI* and *H* values of *kheer* prepared using the widely accepted conventional method (open pan technique) for optimization using hybrid ANN-GA
- Use of FL to analyze sensory data of *kheer* to rank different samples and associated quality attributes prepared at elevated pressures and low cooking times
- Use of hybrid ANN-GA to model and optimize the process parameters of *kheer* prepared at elevated pressures and low cooking times based on desired values of *WI* and *H* obtained above
- Finally, to compare the results of hybrid ANN-GA and FL to decide upon the optimum pressure–time combination for the pressurized cooking section.

2. Materials and methods

2.1. Raw materials for kheer preparation

Kheer samples were prepared using cow milk (3.5 g fat/100 g), *Badshabhogh* rice (short grain, aromatic, raw variety) and refined (powdered) sugar. The raw materials were procured from the local markets of Kharagpur, West Bengal, India.

2.2. Kheer prepared in open pan

For the present study, 7 g of rice and 10 g of refined sugar was added per 100 g of milk (Aneja et al., 2002; Kumar et al., 2005). Rice grains were pre-cleaned, washed twice with tap water and were added to the milk. Open pan preparation of samples were carried out in a stainless steel container (diameter–180 mm, height–100 mm) using an induction heater (Induction Cook-Top PIC 3.0 V2, Prestige) as the heat source with continuous stirring and scraping using a stainless steel spoon. The mixture was gently simmered at 350 W for 30, 35, 40, 45, 50, 55 and 60 min respectively. The temperatures at the completion of the cooking process were measured as 95 ± 2 °C. Refined sugar was added toward the end of the cooking process with continuous stirring and scraping for a period ranging between 30 s and 60 s. Several batches of *kheer* samples were prepared and stored at 4 ± 1 °C for sensory trials. For the purpose of Color and Hardness measurements, three replicates of the experiment were conducted (see Sections 2.5 and 2.6).

2.3. Kheer prepared at elevated pressures

For cooking at elevated pressures, an indigenous pressure-cooking vessel (Pasteur Engineering Pvt. Limited, Kolkata) was used. The indigenous pressure-cooking vessel comprises a steam-jacketed vessel made of stainless steel. Steam generated inside a pressurized boiler is fed in between the walls of the steam-jacketed vessel. Steam condenses between the walls and heats up the water kept inside the vessel, which generates vapors to attain the pressure within the vessel. Required pressure inside the vessel is maintained by controlling the amount of steam that is fed in between the vessel walls from the boiler. As in open pan experiments, pre cleaned and washed rice was added to milk in a stainless steel container (diameter–180 mm, height–100 mm) according to the composition mentioned in Section 2.2 and kept inside the pressure-cooking vessel. A Full-Factorial design of experiments was conducted for different values of pressure and cooking times. Table 1 shows the Full-Factorial design that was used for preparing samples in the pressure-cooking vessel. As mentioned previously, the two independent variables needed in the design of the pressurized cooking section of the continuous *kheer* making machine are operating pressure and cooking time. Operating pressures were considered in the range 0.16 MPa absolute pressure–0.31 MPa absolute pressure (in steps of 0.03 MPa) and cooking time from 6 to 10 min (in steps of 2 min) resulting in a total of 18 experiments. The temperature of the product after taking it out from the pressure-cooking vessel was measured as 95 ± 3 °C. Thereafter, refined sugar was added with continuous stirring and scraping periods ranging between 30 s and 60 s. Again, several batches of *kheer* were prepared and stored at 4 ± 1 °C for sensory trials. For the purpose of Color and Hardness measurements, three replicates of the experiment were conducted.

2.4. Sensory trials of kheer samples

The sensory trials on different product variants were performed on a panel of twenty five members following the Standard Practice for Serving Protocol for Sensory Evaluation of Foods and Beverages