Design and Development of a Continuous Ohmic Heating System for Thermal Processing of Pineapple Juice

ABSTRACT

Ohmic heating is a novel thermal technology in which food materials are kept in between two electrodes, and an electric current is passed through it. The food materials, acting as resistance and completing the electrical circuit, are heated volumetrically and rapidly by the joules effect depending on the electrical conductivity (EC) of the food and electric field strength (EFS) supplied. For uniform heating and continuous thermal processing of pumpable food, a continuous ohmic heating (COH) system is desirable. The COH has the potential to overcome the limitations of conventional thermal processing including non-homogeneity of heat transfer and a significant temperature gradient within the food matrix. Therefore, the present research comprises a total of five objectives, beginning with the development of a lab-scale COH cell and studying its heating performance with different fruit juices. Further, an isothermal holding chamber was developed to equip the COH cell. Quality parameters like colour and vitamin C, enzyme and microbial inactivation were studied under different COH treatment conditions, and the process parameters were optimized. Then, different kinetic models were fitted to enzyme and microbial inactivation and vitamin C degradation. Finally, the storage study of COH-treated (optimized level), conventional water bath-treated and untreated pineapple juice was conducted at two different temperatures.

The COH system consisted of two parts, viz., a heating cell and an isothermal holding chamber. Teflon was used to fabricate both the chambers, which had a hollow cylindrical shape. Two platinized titanium electrodes were fixed at both ends of the heating cell. The isothermal holding chamber was placed perpendicular to the heating cell and connected with a T-shaped jointer. The other accessories included were a K-type thermocouple, a variac transformer (0-500 V, 1φ, 50 Hz), a temperature controller, a peristaltic pump, and a multimeter. Five different fruit juices viz., cucumber, tomato, orange, pineapple, and lemon and three different standardized pineapple juice based on °Brix/Acid viz., 18, 22, and 26 °Brix/Acid were used for the performance evaluation of COH cell at different EFS (25 to 45 V/cm) and flow rate (80 to 120 mL/min). Come-up time (CUT) significantly ($p < 0.05$) decreased with an increase in EFS, resulting in a significant ($p < 0.05$) increase in heating rate (HR) with an increase in EFS. Also, the CUT period increased with an increase in flow rates at lower EFS, while the effect was

non-significant at higher EFS. The change in the °Brix/Acid ratio of the pineapple juice also had a significant effect on the CUT period, and therefore, HR significantly ($p < 0.05$) reduced with an increase in the °Brix/Acid. The variations in the CUT period and the HR among the different fruit juices were observed because of the fruit juice's intrinsic properties like acid content, EC at room temperature, sugar content, consistency/viscosity, and ionic concentrations. The results also showed that the EC had a linear relationship with the temperature during COH of all the fruit juices except the tomato juice, which was better explained with a second-order polynomial relationship with the temperature. The COH system was found to be highly energy efficient with an efficiency of more than 90% can be achieved. However, the efficiency was significantly affected by the variations in the EFS, flow rates, and °Brix/Acid. The efficiency can be further increased with proper insulation of the heating cell and appropriate equipment design.

Standardized pineapple juice (22 °Brix/Acid) was ohmically treated at different EFS (30, 35, and 40 V/cm), temperature (70, 80, and 90 °C), and time (0, 15, 30, 45, and 60 s). The effect of COH treatment on quality parameters (colour and vitamin C), enzyme inactivation (PPO, POD, and bromelain), and microbial inactivation in standardized pineapple juice was studied. The juice sample was ohmically heated in the COH cell to a desired temperature and then passed to the isothermal holding chamber. The sampling was done from the outlet port of the holding chamber and immediately cooled in the ice bath. Significant ($p < 0.05$) reduction in PPO, POD, bromelain, microbial load, and vitamin C content was observed during the CUT period and isothermal treatment at different EFS and temperatures. Time and temperature had a significant ($p < 0.05$) effect on enzyme and microbial inactivation. A minimum residual activity of 31.8 ± 0.8, 17.8 ± 0.4 and 1.2 ± 0.4% was observed for PPO, POD, and bromelain, respectively, at 90 °C, 60 s, and 40 V/cm. It was also observed that the inactivation of the POD enzyme was higher than PPO under each treatment condition suggesting that the PPO was thermally more resistant than the POD enzyme in the pineapple juice. A maximum microbial load reduction of 4.32 ± 0.03 log CFU/mL was observed at 90 °C when treated for 60 s at 35 V/cm. More than 50% of bromelain was inactivated during the CUT period and almost completely inactivated during isothermal treatment, suggesting the highly thermal sensitivity of the enzyme. A significant ($p < 0.01$) effect of treatment parameters was also observed on the overall colour change.

The kinetic modelling of enzymes (PPO, POD, and bromelain), microbial inactivation, and vitamin C degradation of the COH-assisted isothermal treatment of standardized pineapple juice were carried out. The Weibull distribution model showed the highest fitting accuracy for PPO inactivation ($R^2 > 0.990$; RMSE < 0.0101; $\Delta_i \leq 2$), POD inactivation ($R^2 > 0.980$; RMSE < 0.042; $\Delta_i \leq 2$), bromelain inactivation ($R^2 > 0.990$; RMSE < 0.0293; $\Delta_i \leq 2$), and microbial inactivation ($R^2 > 0.980$; RMSE < 0.0085; $\Delta_i \leq 2$) on the given dataset. On the other hand, the first-order model was best suited for vitamin C degradation kinetic ($R^2 > 0.840$; RMSE < 0.057; $\Delta_i = 0$). The accuracy factor (A_f) and bias factor (B_f) for respective models of PPO, POD, bromelain, microbial inactivation, and vitamin C degradation were closer to the simulation line (closer to 1), suggesting the accuracy of these models in predicting. The Weibull model's scale factor (δ-values) also suggested higher thermal stability of the PPO enzyme than the POD enzyme because of the complex nature of these enzymes. Also, the shape factor ($n < 1$) suggested the concave nature of the fitted model.

Also, a second-order polynomial model fits well at a significance level of 5.0% with a full factorial design of experiments. The process parameters of COH-treated standardized pineapple juice were optimized using food spoilage enzymes PPO and POD and total microbial load. The best solution was obtained at EFS 40 V/cm with a treatment temperature of 88.86 °C and a time of 59.94 s. The optimized parameters were validated under similar treatment conditions with a deviation of less than 5.0%.

Further, the standardized pineapple juice was treated under optimized conditions by COH and hot water bath (HWB). The treated juice samples were stored for two months (60 days) at two different temperatures (4 °C and 25 °C), and a comparative storage study was done. The physicochemical parameters like pH, TSS, titratable acidity, EC, and colour of untreated pineapple juice stored at 25 °C were significantly affected, while the change was minor in COH and HWB treated juice samples at both storage temperatures. Slow degradation of enzyme activity (PPO, POD, and bromelain) and vitamin C content was observed during the storage period at both temperatures; however, the degradation was faster at a higher storage temperature of 25 °C than at 4 °C for all the samples. The microbial load increased significantly with the storage period. The microbial load of COH-treated pineapple juice was comparatively lower than the water bath-treated juice samples. However, the increase in the microbial load of COH and HWB treated pineapple juice was within the acceptable limit for human consumption. Thus, the COH process is an energy-efficient, quick and uniform heating of the fruit juice with a negligible thermal gradient within the food samples and a convenient method for processing pineapple juice.