Chapter V

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Ohmic heating setup with data acquisition system was developed having volumetric capacity of 50 mL. The heating behaviour of different food materials was analysed at different EFS. The watermelon juice and litchi juice was found to have highest and lowest electrical conductivity among the selected fruit products. Therefore watermelon heated rapidly whereas the litchi juice heated slowly during OH. The physico-chemical properties such as acidity and consistency of the food material define its OH behaviour. The effect of viscosity on the OH rate was considerably evident at higher EFS, however at lower EFS the effect of viscosity on heating behaviour was not observed. The study revealed that an energy efficiency of more than 90 % is achievable by OH method of heating. The loss of energy can be minimized thus, can be the processing cost.

Further the motive of present research was to verify the possibility of OH as an alternative thermal processing method of mango puree. Thus, before optimizing the OH parameters for mango puree, it was standardized based on two parameters viz acid and soluble sugar (TSS) content which is used as industrial characterization of fruit juice and puree. Soluble sugar and acid content changed the water activity of the mango puree, the change in acid content by 0.12 g/100 g increased the water activity from 0.983 to 0.990. The added sugar binds the free water present in food material hence, makes it unavailable or reduces the water activity. However addition of acid released some water present in the matrix of the fruit material, thus, accounts for increasing the water activity.

The flow and textural characteristics were affected considerable by the soluble solids and acid content. The interaction of sugars and acid with other components such as water, pectin and cell wall material at the molecular level could be the reason for the changes in physico-chemical properties. The onset and peak temperatures of phase change in the mango puree were ranged in between 65-70 and 95-105 °C, respectively, as the acid content increasing and 70-90 °C and 105-110 °C, respectively, as the TSS increasing from 20 to 24°B. However, the sugar addition caused decrease in the enthalpy of fusion probably due inferring effect of sugar on fusion of other species or may be due to the lower mobility of the sugar. The mango puree exhibited visco-elastic nature and the addition of acid caused a slight increase in storage modulus (G’) and loss modulus (G’’) at 30 °C, whereas at 90 °C, relatively higher increase was observed in G’’ (782 Pa) and G’ (129 Pa). The change in soluble solids from 20 to 22 °B increased the G’ and G’’ (dynamic moduli) at 30 and 90 °C, however, further increase in TSS from 22 to 24 °B resulted in the reduction of dynamic moduli. The ohmic heating (OH) behaviour of the mango puree gets affected by electric field strength; however mango puree can be heated instantly by OH at 20-40 V/cm. At 40 V/cm the heating rate of 1.71 and 4.70 °C/s was observed for 0.50 and 0.62 g/100g acid respectively, whereas increasing TSS from 20 to 24 °B caused reduction in heating rate from 2.24 to 1.71 °C/s. The information would be useful designing an alternative thermal processing method for mango puree by the application of OH and, at the same time considering the role of sugar and acid content. The standardized mango puree (0.5 % acid content and 20 °B TSS) was further used for the OH assisted thermal processing in the present study.

To optimize the process parameters of OH processing for mango puree, three level factorial RSM design was used. Although the most desirable condition suggested by the RSM design was OH at 95 °C for 1.942 min using EFS 15 V/cm. However after analyzing the desirability and the process parameters of the first and seventh suggested conditions, it was found that the time of treatment can be reduced by 9.25 % at the compromise of 0.132 % reduction in desirability between the two conditions, the PPO, POD and microbial activity was higher by just 2.7, 1.7 % and 0.001 %, respectively. Whereas, lesser color change was at the seventh suggested condition as compared to the first one. Hence the seventh suggested condition was considered and selected as the optimized condition, with the desirability of 0.794 and the processing conditions were 95 °C for 1.91 min (115 s) at 15 V/cm EFS. Additionally the validation of the data was carried out by checking the experimental and predicted value in the optimization condition at a significance level of 95 %. The results were found to be within the confidence range.

Thermal denaturation of enzymes occurs because of relocation and or destruction of non-covalent bonds such as hydrogen bonds, hydrophobic interactions, and ionic bonds of the tertiary protein structure. However, during OH the presence of electric field effects the biochemical reactions by altering molecular spacing and increasing inter-chain reactions, thus, the enzyme inactivation by OH is reported to be more complex. The inactivation of PPO and POD enzymes during OH of mango puree was fitted to various kinetic models reported. The PPO inactivation was best fitting with the Distinct isozyme model. It suggests that the enzyme inactivation occurs by the sum of two exponential decays, one is thermo-labile (rapid inactivation) and the other is thermo-resistant (slow inactivation). The D value of both the fractions was observed to reduce considerably with increasing the EFS. However, the POD inactivation was observed to follow Weibull model.

The initial count of the bacteria was quiet inconsistent and it ranged from 2.64 to 2.71 log CFU/mL, possibly due to the variations in sample like contamination, source and may be handling etc. The microbial population was observed to decrease with the treatment time and temperature, also the increase in EFS caused increased destruction of microbial population.

The change in color of the mango puree during heating may occur due to many reasons such as Maillard reaction, cooking, caramelization etc. The most critical reason for change in color is the alterations in the pigment, β-carotenes during processing. The ΔE was increasing with the temperature at all the EFS, the change was observed to follow linear pattern with the heating time. The effect of temperature in color degradation was lower at lower EFS and higher at the higher EFS

Further, in the present study, the mango puree was treated by the OH optimized condition and compared with the conventional hot water heating method (HW). The effects of come up time and holding time on various important parameters was studied and compared. Both OH and HW thermal treatment caused the reduction in acidity the changes acidity may be due to the degradation of heat sensitive organic acids present in mango such as ascorbic acid. Relatively higher change in acidity was observed in OH treatment as compared to its HW counterpart. The higher changes in pH and acidity during OH may be due to some electro-chemical changes induced by the electric current during OH treatment. Both the heat treatments OH and HW were found to cause slight changes in the flow pattern or slight reduction in the viscosity of the mango puree. The damage caused by the thermal treatment to the solid fraction components of the mango puree may be the reason for the slight changes in the flow behavior of mango puree.

The come up time (CUT) of hot water heating (HW-0) and ohmic heating (OH-0) caused a loss of approximately 40 and 17 % in ascorbic acid respectively. The holding period of 115 s at 95 °C resulted in further loss up to 58 and 42 % in HW and OH treatments respectively. The lower damage of ascorbic acid during OH should be due to the uniform heating and also during OH the pathway of ascorbic acid degradation gets interrupted.

The presence of carotenes and phenolic compounds make mango products rich in antioxidant. However, the losses of these bioactive compounds due to processing need therefore to be minimized. The TPC loss during the CUT period of HW and OH treatment was found to be 13.07 % and less than 5 % respectively. However heating further for holding time caused additional reduction but the reduction was relatively lower than caused by CUT period. The OH was observed to result in a higher reduction in β-carotene than that of HW treatment. The CUT period of OH and HW resulted in reduction of 11.97 and 5.63 % of β-carotene respectively. Reduction in β-carotene was observed to be 14.44 and 9.23% by OH and HW respectively while heating further at 95 °C for 115 s.

The glass vials filled with treated mango puree were stored for 3-months at room temperature (23±2 °C). There was no significant difference observed in the flow behavior index 'n' and consistency coefficient "k' in either of the treated mango puree during the storage. However, it was found that the yield stress (σ_0) continuously decreased with the storage time in both OH as well as HW treated samples. The enzyme and microbial action on the dispersed phase (particle phase) including the cell walls, insoluble polymer clusters and chains should also have a good contribution in the reduction of yield stress during storage. The pH reduced to 2.95 and 3.64, whereas the acidity increased to 0.636 and 0.545 % in HW and OH treated samples respectively during storage. The increase in acidity during storage may be due to the growth of acid-forming bacteria. Also, increase in acidity could be attributed to the reaction of basic amines to convert into the compounds of lower basicity and to the degradation of sugars into acids during the Maillard reaction. Higher amount of TPC was retained in OH treated samples than that of HW treated. The reduction in storage was found to be 32.77 and 20.48 % in HW and OH treated samples respectively. The loss of β–carotene generally is due to auto-oxidation, the highly unsaturated chemical structure of β–carotenes makes them very susceptible to oxidation, and storage at ambient conditions enhances the rate of oxidation than at lower storage temperature. During the storage, the β–carotenes were found to reduce significantly ($p<0.05$) in both HW and OH treated samples. The reduction of 14.27 and 15.20 % was recorded in β–carotenes in HW and OH treated samples respectively during the storage of three months. However, there was no difference in the rate of reduction in β–carotenes between the two treatments. The vitamin C content showed significant reduction during storage in both HW and OH treated samples. The reduction among the treatment methods was not significant as the degradation was calculated to be 24.49 and 25.76 % in HW and OH after three months respectively. The bacterial count was observed to increase with the storage time, the growth was observed to be very fast during the first one month of the storage whereas the rate of bacterial growth reduced after one month and onwards. The reduction in rate of growth could be due to the increase in acidity with the storage. The pattern of increase in the bacterial population was similar in both the treated samples, In HW and OH treated samples, the bacterial count increased from 1.46 to 2.84 and 1.73 to 2.60 log CFU/mL respectively. However, the increase in the bacterial count was within the acceptable limit for human consumption. In summary, the OH process can be proved to be an energy efficient, convenient method of mango puree processing. Additionally, OH would be helpful in retention of quality parameters, thus, it is recommended that the OH process has great potential as an alternative thermal processing method for mango puree.

The future scope of the current research is to study the effect of the frequency of electric current on various parameters of the mango puree during OH. Additionally the shape of wave of alternating current can also be studied to evaluate its effects on mango puree. Changes in the structure of specific microorganism could be studied to verify the structural damages of the microbial cells due to non thermal effects (due to presence of electric field) of OH. The electrochemical effects on specific important nutrients in mango puree during OH should be studied. The storage study of ohmically treated mango puree at elevated temperature could be helpful for exact shelf life estimation; also shelf life in different packaging materials can also be studied.