Degradation kinetics of bioactive components, antioxidant activity, colour and textural properties of selected vegetables during blanching

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Abstract Bioactive components of fruit and vegetables play an important role in scavenging free radicals and protect the body from degenerative diseases. A kinetic study was conducted to quantify the losses occurring in bioactive components, antioxidant activity and changes in colour and firmness of four commonly used vegetables (beetroot, green pea, eggplant and green pepper) during heat treatment (70–90 °C). The study revealed that logistic model can predict the variation in bioactive components and antioxidant activity with higher R^2 and lower root mean square error (RMSE) as compared to first order model due to logarithmic reduction in these properties in the beginning of the process itself. However zero and first order kinetic models were found suitable to predict the changes occurring in colour and firmness respectively during blanching. D , z value, activation energy (E_a), activation enthalpy and entropy were calculated for all measured parameters for selected vegetables in the temperature range of 70–90 °C. These finding would be useful in designing thermal processes and related calculations for these vegetables.

Keywords Beetroot · Green pea · Total phenolic content · Ascorbic acid · Firmness · Thermal resistance time · z value and activation energy

Abbreviations

ROS	Reactive oxygen species
TP	Total phenolic compounds
GAE	Gallic acid equivalents
AsA	Ascorbic acid
AA	Antioxidant activity
DPPH,2,2,	Diphenyl-2-picryl-hydrazyl

Introduction

Bioactive compounds are extra-nutritional constituents, available mainly in fruits and vegetables that impart additional health benefits in human beings. Most of the bioactive components are antioxidants which provide protection against harmful free radicals that contribute to ageing related degenerative diseases (Atoui et al. 2005) and thereby reduce the risk of chronic and cardiovascular diseases, cancer, diabetes, Alzheimer, cataracts and age-related functional decline (Zhang and Hamauzu 2004). Natural antioxidants such as vitamins, carotenoids, flavonoids and other phenolic compounds are available in fruit and vegetables in considerable amounts (Minussi et al., 2003; Zhang and Hamauzu 2004). In recent years, increasing consumers' awareness towards bioactive components and their potential health benefits, has forced them to search for foods which contain more functional bioactive compounds. Thus, food processors are emphasizing upon producing foods with higher bioactive compounds or minimizing the loss in available antioxidants during processing to meet out the current market demand.

Although, vegetables account for a small part of our daily calorie intake (Ismail et al. 2004); yet they are considered to be the major contributors of reactive oxygen species (ROS)-scavenging antioxidants (Jiménez et al.

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2009). While processing, vegetables undergo many operations such as blanching, canning, sterilization and freezing in food industries, as well as cooking at domestic level which are very likely to affect the composition and content of various bioactive components due to thermal degradation, dilution and leaching into the water used for treatment (Chuah et al. 2008; Gonçalves et al. 2010; Ismail et al. 2004; Jiménez et al. 2009; Podsedek 2007; Puupponen et al. 2003; Turkmen et al. 2005; Zhang and Hamauzu 2004). Losses of these nutrients need to be taken into account while developing new products and/or processes. To predict the nutrient losses, the knowledge of kinetics including reaction order, rate constant and activation energy are very vital especially during thermal processing. Kinetic models are used for fast quality assessment and prediction, in addition they can be employed to predict the influence of processing on critical quality parameters.

The kinetics related to nutrients' degradation have been examined in many fruits and their products like blackberry jam (Moura et al. 2012), orange juice (Fратиanni et al. 2010; Vikram et al. 2005), pomegranate arils (Başlar et al. 2014) raspberry pulp (Summen and Erge 2014), wild strawberry pulp (Özgen and Erge 2013), strawberry jam (Patras et al. 2011) and tomato (Marfil et al. 2008) etc. However, meager reports are available on degradation kinetics of nutrient in vegetables during mild heat treatment like blanching; an industrially important thermal process for vegetables. With this purview, a kinetic study was conducted to find out the changes in bioactive components, antioxidant activity, colour and firmness caused by blanching of selected vegetables at different temperature for varied duration.

Materials and methods

Sample preparation and blanching

Four common vegetables viz. Beetroot, green pea, eggplant (brinjal) and green pepper were selected for the study. The vegetables were purchased in fresh form from the local market in Abohar, Punjab at their commercially marketable maturity. The vegetables of uniform size, shape and colour were handpicked and washed in fresh running water. The necessary preparatory steps like peeling (beetroot), depodding (green pea), removal of stalk and other unnecessary parts (eggplant and green pepper) were carried out manually. Cubical pieces of size $5 \times 5 \times 5$ mm from beetroot and eggplant and cuboid pieces of size $5 \times 5 \times 3$ mm from green pepper were made using hand operated dicer. While green peas of uniform diameter (7 ± 0.5 mm) were selected for the study.

For blanching, 150 ml of distilled water was taken in a glass beaker and kept in a thermostatic water bath (WBRT-

12, Macro Scientific Works, India) with the accuracy of 0.5°C . Once the water attained the desired temperature, 50 g of each vegetable (3:1 v/w) were immersed into the beaker for blanching. The blanching was done at five temperatures (70, 75, 80, 85 and 90°C) for 0–15 min and the samples were taken out at 3 min interval. Three different sample lots in three different beakers were made for each vegetable in order to maintain three replication. Based on Gonçalves et al. (2010) and Günes and Bayindirli (1993) who reported the time temperature combination for 90 % inactivation of peroxidase and lipoxygenase in green beans, green pea and carrots, the time and temperature ranges were selected for this study. After blanching, the samples were cooled in iced water ($1\text{--}4^\circ\text{C}$) for 1 min (Jaiswal et al. 2012) and spread over tissue paper for removal of excess moisture.

Total phenolic compounds (TP) determination

The amount of total phenolic content was determined using a colorimetric assay of Folin–Ciocalteu's phenol reagent as described by Singleton and Rossi (1965). The extraction and estimation were done as proposed by Pérez et al. (2009). Finally absorbance was measured at 750 nm in a spectro-photometer (UV-2550, Shimadzu, Kyoto, Japan). Gallic acid with concentration ranging from 8.0 to 40.0 mg/ml were used as standard to prepare the calibration curve ($R^2 = 0.99$). The results were expressed as milligram gallic acid equivalents (GAE) in per 100 g of edible portion (Gahler et al. 2003).

Ascorbic acid (AsA) determination

Ascorbic acid was quantitatively determined by titration using 2,6-dichlorophenolindophenol dye as described by Deepa et al. (2006). The samples (10 g) were homogenized with 10 ml of 3 % meta-phosphoric acid (v/v). The extract was made up to 100 ml and centrifuged at 3000g for 15 min at room temperature. Ten ml of supernatant was titrated against standard 2,6-dichlorophenolindophenol dye, which had already been standardized against standard ascorbic acid. The ascorbic acid content was expressed as mg per 100 g on fresh weight basis.

Antioxidant activity (AA) determination

The antioxidant activity was studied by evaluating the free radical-scavenging effect using DPPH (2,2,-diphenyl-2-picryl-hydrazyl) (Allothman et al. 2010). The absorbance was measured at 515 nm using a UV–Visible spectrophotometer (UV-2550, Shimadzu, Kyoto, Japan) against a blank of methanol without DPPH. Results were expressed as the percentage inhibition of the DPPH radical, which was calculated using the equation:

$$\% \text{inhibition of DPPH} = \frac{\text{Absorbance}_{\text{control}} - \text{Absorbance}_{\text{sample}}}{\text{Absorbance}_{\text{control}}} \times 100 \quad (1)$$

where $\text{Absorbance}_{\text{control}}$ is the absorbance of the DPPH solution without the extracts.

Colour and texture measurements

The colour of vegetables was measured using handy colourimeter (NR300, Nippon Denshoku Ltd., Tokyo Japan) in CIE colour space ($L^* a^* b^*$ co-ordinates). Total color difference (ΔE) was calculated using Eq. 2 (Moura et al. 2012)

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \quad (2)$$

where ΔL , Δa , Δb represent the deviations of the individual values from the respective values of raw sample.

Firmness was measured using texture analyser (TA-XT2, Stable Micro Systems, UK) with 50 kg load cell. Cylindrical probe of 3 mm diameter with flat base was used to obtain force displacement curve at pre-test speed of 0.5 mm/s, test speed of 0.1 mm/s and post-test speed of 1 mm/s up to depth of 1.5 mm in green pepper and 3 mm depth for rest of the vegetables. Maximum force required for penetration was considered as firmness. Mean value was calculated from three measurements from each sample.

Kinetic considerations

A general reaction rate expression for the degradation kinetics can be written as follows (Boekel 1996);

$$-\frac{d[C]}{dt} = k[C]^m \quad (3)$$

where C is the quantitative value (concentration of nutrient), k is the reaction rate constant, and m is the order of the reaction. As reported by number of authors Avila and Silva (1999), Chen and Ramaswamy (2002), Gonçalves et al. (2010), Maskan (2001), Nisha et al. (2004, 2005), Summen and Erge (2014) and Vikram et al. (2005), from Eq. 3, zero order (Eq. 4), first order (Eq. 5) and logistic models (Eq. 6) can be derived as follows

$$C = C_0 + kt \quad (4)$$

$$C = C_0 \exp(-kt) \quad (5)$$

$$C = U_0 + \frac{U}{1 + \exp(-k(t - t_0))} \quad (6)$$

where C_0 is the initial concentration values, U_0 is a constant value related to the initial C value, U is a constant value related to the final C equilibrium value, k is the reaction rate constant, t is the time and t_0 is the time constant value when C value increases(decreases) to half of U value.

Temperature dependence of a reaction is described by the Arrhenius equation:

$$k = k_0 \exp\left(\frac{E_a}{R.T}\right) \quad (7)$$

where, k_0 frequency factor or the Arrhenius constant, R universal gas constant (8.3145 J/mol K), T is the absolute temperature (K) and E_a activation energy kJ/mol. Higher activation energy implies that a smaller temperature change is sufficient for the degradation of a specific compound (Vikram et al. 2005).

The thermal resistance time or decimal reduction time (D values), the time required to reduce the nutrient concentration by 90 %, was related to reaction rate constants by

$$D = \frac{2.303}{k} \quad (8)$$

Thermal resistance temperature (z value) representing the temperature required for 1 log cycle reduction in D value. z value was calculated from linear regression of $\log(D)$ versus temperature. Activation enthalpy (ΔH) and entropy (ΔS) of activation were calculated by regression analysis of $\ln(k)$ on $1/T$ from the equation derived from transition state theory (Ariahu and Ogunsua 2000).

$$\ln\left(\frac{k}{T}\right) = \left[\ln\left(\frac{k_s}{h}\right) + \left(\frac{\Delta S}{R}\right)\right] - \left[\left(\frac{\Delta H}{R}\right) \times \left(\frac{1}{T}\right)\right] \quad (9)$$

where k_s is Boltzmann constant (1.380658E−23 J/K), h Plank's constant (6.6260755E−34 J s) and R universal gas constant.

Statistical analysis

Each experiment was repeated thrice to minimize the errors. A full factorial experimental design was developed for five different time–temperature combinations, with three replications (5 temperatures $\times$ 5 time durations $\times$ 3 replications + 3 raw samples). For each vegetable, 78 samples were taken for extraction and analysis for a single quality parameter. Two way ANOVA with replication was used to test the level of significance of blanching on nutrients, colour and firmness. The observed data were fitted with selected models, regression coefficients and goodness of fit parameters were found using MATLAB. The graphical representations along with the predicted models were prepared using MS-Excel.

Results and discussion

From ANOVA, it was found that changes in bioactive components, colour and textural properties were highly significant over blanching process ($p < 0.01$). The changes

Fig. 1 Changes in total phenolic content and ascorbic acid (mean $\pm$ SD) with its kinetic prediction for **a** beetroot, **b** green pea, **c** eggplant and **d** green pepper (P in the legend denotes predicted line)

in the bioactive components, anti-oxidant activity, colour and textural properties were plotted against blanching time for different temperature (Figs. 1, 2, 3).

Total phenolic content (TP)

The TP contents decreased in all vegetable during blanching (Fig. 1). As time and temperature of blanching increased, the reduction in TP increased drastically. The reduction rate was linear at lower temperature and logarithmic at higher temperature since maximum reduction occurred within 5 min of blanching (Fig. 1). Blanching for short duration (3 min) also reduced the total phenolic contents significantly (~ 15 – 20 % at 70 °C and 50 – 52 % at 90 °C). Similarly, Ismail et al. (2004) reported about high heat sensitivity of phenolic compounds even for a short period of cooking.

Green pea and pepper had recorded the highest loss in TP (~ 75 – 80 %) followed by beet root (~ 70 %) and eggplant (~ 64 %) on 15 min blanching at 90 °C. The observed loss could be due to breakdown of phenolic components (Turkmen et al. 2005) and/or dissolution of polyphenols into the cooking water (Chuah et al. 2008). Similar reduction in total phenolic during cooking of vegetables like broccoli, cabbage, coloured peppers, Irish York cabbage, kale, leek, peas, shallots, spinach, squash, swamp cabbage, tomato and some of selected cruciferous vegetables has been reported by many researchers (Chuah et al. 2008; Gonçalves et al. 2010; Ismail et al. 2004; Jaiswal et al. 2012; Sahlin et al. 2004; Sikora et al. 2008; Turkmen et al. 2005; Zhang and Hamauzu 2004).

Kinetic models were fitted with the experimental data and the best fit results are given in Table 1 with goodness

Fig. 2 Changes in antioxidant activity (Mean $\pm$ SD) with its kinetic prediction for **a** beetroot, **b** green pea, **c** eggplant and **d** green pepper (P in the legend denotes predicted line)

of fit parameters (R^2 and RMSE) and in Table 2 with regression coefficient. Among the kinetic models studied, logistic kinetic model was found suitable in most of the cases for predicting the changes in TP with higher R^2 and lower RMSE values during blanching of selected vegetables. At 70 °C temperature, the change in TP was predicted using first order model with relatively better goodness of fit parameters. But at higher temperatures, logistic model predicted the variation with higher R^2 values as compared to first order model due to logarithmic reduction in TP in the beginning of the process. The same can be observed from Fig. 1. Thermal resistance time (D) and temperature (z) values for TP for the selected vegetables are given in Table 3. The D value decreased with increase in the blanching temperature. Higher z value was found for TP of beet root while the lowest was with that of green peas. Activation energy for the total phenolic content varied from 36.84 to 78.21 kJ/mol. Activation enthalpy and entropy ranged from 0.06 to 0.16 kJ/mol K and 35.68 to 71.58 kJ/mol K, respectively (Table 3).

Ascorbic acid (AsA) content

The changes in ascorbic acid content during blanching of selected vegetables are shown in Fig. 1. Alike TP, ascorbic acid also decreased throughout the blanching process. The magnitude of loss was more at higher temperature and treatment time (Fig. 1). At higher blanching temperatures (85 and 90 °C), the loss in ascorbic acid was higher within 5 min of blanching. Higher loss was observed in green pea and eggplant (~65–70 %) followed by beetroot and green

pepper (~50 %) during blanching of the vegetables at 90 °C for 15 min.

Similar decreasing trend in ascorbic acid content during thermal treatment has earlier been reported in broccoli (Zhang and Hamauzu 2004), colour peppers (Chuah et al. 2008), orange juice (Vikram et al. 2005) and tomato (Marfil et al. 2008). The loss of ascorbic acid is due to accelerated oxidation which lead to the conversion of ascorbic acid to dehydroascorbic acid followed by hydrolysis to 2,3-diketogulonic acid and eventually polymerization during thermal process (Gregory 2007). Degradation of ascorbic acid during boiling or blanching is also due to leaching of ascorbic acid from the plant tissues into the cooking water (Somsu et al. 2008).

Except green pea, the changes occurring in ascorbic acid were well predicted with first order model at lower blanching temperatures (Table 1). Rest of the changes were quite predictable with logistic model, since the reduction in AsA was higher in the beginning of the blanching process. The same is depicted in the Fig. 1.

Alike TP, the D values for ascorbic acid decreased with increase in blanching temperature (Table 3). The z value ranged from 15.45 to 26.32 °C. These results are comparable with results reported in orange with a z value of 27.15 and 24.39 °C (Van den Broeck et al. 1998; Vikram et al. 2005) and in tomatoes 30.15 °C (Van den Broeck et al. 1998). Lowest z value was found with green pepper which revealed that ascorbic acid in green pepper was more sensitive to heat than other vegetables. The activation energy for the ascorbic acid varied from 44.94 to 70.41 kJ/mol. The activation enthalpy ranged from 0.10 to

Fig. 3 Changes in total colour difference and firmness (Mean $\pm$ SD) with its kinetic prediction for **a** beetroot, **b** green pea, **c** eggplant and **d** green pepper (P in the legend denotes predicted line)

0.17 and entropy ranged from 36.19 to 64.05 kJ/mol K. These results are in accordance with the activation enthalpy and entropy of vitamin C of orange juice of 0.11 and 61.60 kJ/mol K (Vikram et al. 2005).

Anti-oxidant activity (AA)

The changes in antioxidant activity during blanching are shown in Fig. 2. Alike TP and ascorbic acid, the anti-oxidant activity of green pea, eggplant and green pepper reduced during blanching. These results are in conformity with the results reported by Jiménez et al. (2009), Jaiswal et al. (2012), Papetti et al. (2002) and Podsedek (2007) who reported that the heat treatments affect the antioxidant activity of vegetables. Similar reducing trend have been

reported in many vegetables by Chuah et al. (2008), Ismail et al. (2004), Puupponen et al. (2003) and Zhang and Hamauzu (2004). The loss in AA might be due to degradation and/or leaching of certain types of phenolic compounds or other compounds responsible for DPPH RSC into the boiling water during blanching (Chuah et al. 2008; Jaiswal et al. 2012).

Contrarily in beetroot, increase in AA was observed during blanching. Blanched beetroot exhibited about 10 % higher anti-oxidant activity as compared to its raw counterpart. Jiménez et al. (2009) reported that beetroot retained anti-oxidant activity during most of the cooking methods. Turkmen et al. (2005) reported an increase in anti-oxidant activity of pepper, squash, green bean and spinach during boiling of these vegetables. The increase in antioxidant

Table 1 Goodness of fit values of kinetic models for prediction of changes in quality parameters during blanching of selected vegetables at different temperature

Vegetable	Total Phenolics			Ascorbic acid			Anti-oxidant activity			Total Colour Difference			Firmness		
	Temp. (°C)	R ²	RMSE	Temp. (°C)	R ²	RMSE	Temp. (°C)	R ²	RMSE	Temp. (°C)	R ²	RMSE	Temp. (°C)	R ²	RMSE
Beetroot	70 _(1st)	0.99	0.01	70 _(1st)	0.96	0.08	70 _(log)	0.94	0.87	70 _(z)	0.96	2.18	70 _(1st)	0.96	2.34
	75 _(log)	0.96	0.03	75 _(1st)	0.96	0.11	75 _(log)	0.94	1.03	75 _(z)	0.87	3.02	75 _(1st)	1.00	0.64
	80 _(log)	0.99	0.02	80 _(1st)	0.96	0.12	80 _(log)	0.95	1.13	80 _(z)	0.85	3.57	80 _(1st)	0.98	1.55
	85 _(log)	0.99	0.02	85 _(log)	0.97	0.20	85 _(log)	0.96	1.21	85 _(log)	0.97	2.04	85 _(1st)	0.95	2.14
	90 _(log)	0.99	0.02	90 _(log)	0.96	0.32	90 _(log)	0.97	1.26	90 _(log)	0.97	1.99	90 _(1st)	0.97	1.81
Green pea	70 _(1st)	0.96	0.01	70 _(1st)	0.99	0.22	70 _(1st)	0.94	0.67	70 _(z)	0.99	0.39	70 _(1st)	0.93	0.37
	75 _(log)	0.96	0.02	75 _(log)	0.98	0.27	75 _(1st)	0.92	1.33	75 _(z)	0.98	0.43	75 _(1st)	0.96	0.66
	80 _(log)	0.99	0.01	80 _(log)	0.96	0.41	80 _(1st)	0.97	1.03	80 _(z)	0.96	0.54	80 _(1st)	0.97	1.24
	85 _(log)	0.98	0.02	85 _(log)	0.97	0.38	85 _(1st)	0.93	1.30	85 _(z)	0.96	0.77	85 _(1st)	0.95	1.63
	90 _(log)	0.98	0.02	90 _(log)	0.99	0.30	90 _(1st)	0.94	1.32	90 _(z)	0.94	1.15	90 _(1st)	0.95	2.20
Egg plant	70 _(1st)	0.98	0.01	70 _(1st)	0.98	0.12	70 _(1st)	0.97	0.30	70 _(z)	0.99	0.98	70 _(1st)	0.97	1.05
	75 _(1st)	0.97	0.01	75 _(log)	0.98	0.17	75 _(1st)	0.95	0.68	75 _(z)	0.98	1.31	75 _(1st)	1.00	0.56
	80 _(log)	0.91	0.02	80 _(log)	0.90	0.41	80 _(log)	0.92	0.99	80 _(z)	0.96	1.99	80 _(1st)	0.97	0.79
	85 _(log)	0.98	0.01	85 _(log)	0.96	0.26	85 _(log)	0.96	1.21	85 _(z)	0.90	3.15	85 _(1st)	0.95	1.48
	90 _(log)	0.98	0.01	90 _(log)	0.99	0.18	90 _(log)	0.97	1.24	90 _(z)	0.93	3.02	90 _(1st)	0.93	2.26
Green pepper	70 _(1st)	0.93	0.02	70 _(1st)	0.99	0.07	70 _(log)	0.99	0.44	70 _(z)	0.94	0.25	70 _(1st)	0.95	0.48
	75 _(log)	0.99	0.01	75 _(1st)	0.94	0.21	75 _(log)	0.99	0.52	75 _(z)	0.98	0.13	75 _(1st)	0.96	0.41
	80 _(log)	0.97	0.03	80 _(log)	0.99	0.12	80 _(log)	0.98	0.78	80 _(z)	0.92	0.24	80 _(1st)	0.92	0.52
	85 _(log)	0.98	0.02	85 _(log)	0.97	0.34	85 _(log)	0.98	1.10	85 _(z)	0.98	0.14	85 _(1st)	1.00	0.17
	90 _(log)	0.99	0.02	90 _(log)	0.97	0.40	90 _(log)	0.98	1.19	90 _(z)	0.98	0.15	90 _(1st)	1.00	0.10

R²: coefficient of determination; RMSE: root mean square error; subscript z: zero order kinetic model; 1st: first order kinetic model; log: logarithmic kinetic model

activity of vegetables at high temperatures may be due to inactivation of oxidative enzymes like peroxidases which is responsible for pro-oxidant activity (Gazzani et al. 1998; Yamaguchi et al. 2001). Besides, improvement in antioxidant properties may be due to naturally occurring compounds or formation of novel compounds during thermal processing such as product of Maillard reaction which has antioxidant property (Manzocco et al. 2000; Turkmen et al. 2005).

The results of kinetic modeling of antioxidant activity studies are given in Table 2. Among the kinetic models selected, logistic kinetic model was found more suitable in for predicting the changes in AA with higher R² and lower RMSE values during blanching. But, in case of green peas, first order model was found sufficient to describe the changes in AA during blanching (Fig. 2). Since AA of beetroot increased during blanching, it had higher D values with the range of 181.20–281.88 min (Table 3) than other vegetables. The z value for AA ranged from 16.33 to 45.50 °C. The activation energy, enthalpy and entropy for AA were 22.70–65.08 kJ/mol, 0.11–0.23 kJ/mol K and 19.83–60.39 kJ/mol K, respectively.

Colour and textural properties

The changes in total colour difference (ΔE) and firmness occurring in vegetables during blanching are given in Fig. 3. An increase in ΔE was observed during blanching in all selected vegetables. Blanching caused a reduction in all CIE colour coordinates (L , a and b), which led lead to increase in ΔE in all vegetables and this might be due to leaching and migration of colour pigments into the blanching water (Jaiswal et al. 2012). Gonçalves et al. (2010) reported that the colour pigments are highly influenced by heat. The changes in ΔE were higher for long blanching duration and higher temperature than short duration and low temperature.

The changes occurred in total colour differences during blanching of selected vegetables were well predicted with zero order model (Tables 1, 2) and the same could be observed from Fig. 3. Interestingly, an increase in D value for the total colour difference was found in beetroot with increasing temperature (Table 3). The z value for total colour difference ranged from 23.73 to 39.65 °C. The activation energy for colour difference

Table 2 Regression coefficients of kinetic models for prediction of changes in quality parameters during blanching of selected vegetables at different temperature

Vegetable	Temp. (°C)	Total phenolics			Ascorbic acid			Anti-oxidant activity			Total colour difference			Firmness				
		a	b	c	k	a	b	c	k	a	b	c	k	a	k			
Beetroot	70	0.4			0.1	5.8			−0.1	−528.5	575.5	−25.3	0.2	100.2	0.0	7.4	2.0	
	75	35.6	−35.5	−15.8	0.3	5.7			−0.1	−883.5	931.2	−18.2	0.3	100.3	0.0	13.9	1.8	
	80	6.5	−6.4	−4.1	0.8	5.7			0.0	−1253.0	1302.0	−14.4	0.4	99.3	−45.8	0.0	18.3	2.0
	85	12.7	−12.6	−5.9	0.6	3.9	204.6	−15.6	−0.3	−587.1	637.4	−9.3	0.5	126.0	−48.5	0.4	24.7	1.8
	90	12.0	−11.9	−5.6	0.7	3.2	268.8	−13.6	−0.3	−574.1	626.0	−7.5	0.5	127.6	0.5	25.5	2.1	
Green pea	70	0.3			0.0	208.7	−205.9	−18.3	0.2	29.7			0.0	17.5	0.0	4.1	0.2	
	75	20.4	−20.3	−17.6	0.3	269.3	−266.2	−12.8	0.4	29.4			0.0	17.0	0.0	3.5	0.6	
	80	9.3	−9.2	−10.4	0.4	2.6	283.3	−11.2	−0.4	30.1			0.0	16.9	−16.7	0.0	1.4	1.3
	85	7.1	−7.0	−6.1	0.6	277.7	−275.4	−11.7	0.4	29.2			0.0	25.1	−17.8	0.2	4.3	1.3
	90	7.7	−7.7	−5.8	0.6	1.9	147.4	−6.8	−0.5	29.0			0.0	25.8	0.4	1.3	1.7	
Egg plant	70	0.2			0.0	3.2			−0.1	23.5			0.0	35.8	0.1	3.3	1.2	
	75	0.2			0.1	1.3	165.4	−19.3	−0.2	24.1			0.0	34.7	0.1	4.9	1.7	
	80	17.2	−17.0	−20.8	0.2	339.3	−338.2	−26.7	0.2	429.1	−411.6	−20.4	0.2	34.0	0.1	5.9	0.8	
	85	6.8	−6.7	−7.5	0.5	222.0	−220.9	−13.2	0.4	545.1	−531.1	−9.0	0.4	32.8	0.1	14.8	1.2	
	90	8.5	−8.4	−8.4	0.5	78.9	−78.0	−5.6	0.6	586.9	−574.1	−7.9	0.5	33.7	0.1	15.5	1.5	
Green pepper	70	0.4			0.0	8.8			−0.1	145.2	−110.3	−13.6	0.2	3.0	0.1	0.2	0.4	
	75	17.7	−17.6	−18.0	0.2	8.3			0.0	446.3	−413.2	−18.2	0.2	2.9	0.1	1.2	0.4	
	80	28.1	−28.0	−12.9	0.4	122.9	−116.6	−28.1	0.1					2.7	0.1	0.7	0.3	
	85	9.2	−9.0	−5.2	0.7	232.2	−227.2	−27.4	0.2					2.8	0.2	1.5	0.5	
	90	0.1	9.3	−5.6	−0.6	322.9	−318.7	−22.8	0.2					2.8	0.2	1.9	0.5	

Table 3 Thermal resistance time (*D*), thermal resistance temperature (*z*), activation energy (*E_a*), enthalpy (ΔS) and entropy (ΔH) values of bioactive components, colour and textural properties of selected vegetables

Component or property	Vegetable	D value (min)					Z (°C)	R ²	<i>E_a</i>	R ²	ΔS	ΔH
		70 °C	75 °C	80 °C	85 °C	90 °C						
Total phenolics	Beetroot	35.47	28.40	22.33	19.44	16.90	26.86	0.98	36.84	0.99	0.16	35.68
	Green pea	58.54	35.92	23.66	22.59	12.22	13.90	0.95	78.21	0.94	0.06	71.58
	Egg plant	60.56	49.09	44.57	33.00	22.48	21.02	0.95	56.22	0.95	0.14	46.16
	Green pepper	54.28	40.08	26.39	19.24	15.07	15.16	0.99	65.38	0.99	0.08	65.39
Ascorbic acid	Beetroot	185.88	126.26	118.77	82.13	51.85	16.76	0.95	70.41	0.96	0.11	58.70
	Green pea	41.40	46.24	33.08	28.74	20.31	26.32	0.86	44.94	0.90	0.17	36.19
	Egg plant	40.47	35.19	29.82	24.59	15.88	22.42	0.94	53.76	0.93	0.15	43.04
	Green pepper	183.21	129.89	97.58	71.46	48.96	15.45	0.99	69.86	0.99	0.10	64.05
Colour change	Beetroot	31.42	38.90	42.97	54.39	49.91	39.65	0.86	28.19	0.90	0.35	29.17
	Green pea	61.69	36.40	23.12	30.45	24.37	24.56	0.66	32.48	0.58	0.16	39.61
	Egg plant	26.79	27.68	38.54	51.21	45.57	29.81	0.83	35.41	0.87	0.38	37.76
	Green pepper	23.55	29.37	23.54	28.34	30.50	23.73	0.78	22.89	0.77	0.30	12.88
Firmness	Beetroot	86.40	81.41	80.51	76.05	73.22	55.71	0.85	13.22	0.84	0.28	8.46
	Green pea	60.08	53.72	51.59	49.20	38.61	44.91	0.42	16.40	0.48	0.24	10.63
	Egg plant	32.50	27.97	25.55	26.41	22.30	51.69	0.87	16.64	0.87	0.23	13.87
	Green pepper	25.54	21.80	25.05	15.47	14.07	32.56	0.77	34.68	0.82	0.18	28.71
Antioxidant activity	Beetroot	281.88	248.97	224.46	200.78	181.20	45.50	0.99	22.70	0.99	0.23	19.83
	Green Pea	135.23	73.53	59.69	65.61	62.63	30.24	0.61	25.67	0.57	0.19	31.71
	Egg plant	176.07	102.81	120.77	60.34	49.74	16.33	0.88	65.08	0.91	0.11	60.39
	Green pepper	205.63	157.42	154.25	106.67	90.35	24.58	0.95	43.54	0.96	0.17	39.13

*R*²: coefficient of determination; *E_a*: activation energy; ΔS : activation enthalpy; ΔH : activation entropy

was 9.89–35.41 kJ/mol. Similar to these results, activation energy of colour change in York cabbage has been reported to be around 15.73 kJ/mol during blanching (Jaiswal et al. 2012). The activation enthalpy and entropy varied from 0.16 to 0.38 kJ/mol K and 12.88 to 37.76 kJ/mol K, respectively.

The firmness of selected vegetables decreased with increase in time and temperature of blanching. During thermal processing, a range of chemical reactions occur, such as solubilisation and depolymerisation of pectic polysaccharides, which affect the constituents of the cell wall and middle lamella, thereby resulting in a major change in the firmness of fruits and vegetables (Jaiswal et al. 2012; Nisha et al. 2006). At 85 and 90 °C, the reduction in firmness was higher in the beginning of blanching process itself (within 5 min). On the other side, a linear decreasing trend was observed at lower blanching temperatures (Fig. 3). Highest reduction (~90 %) in firmness was observed with green pepper followed by eggplant (~80 %) and green pea (~60 %) while comparatively low reduction (~25 %) was observed in beetroots.

The change in firmness during blanching of selected vegetables were well defined with first order kinetic model

(Table 1) except for beetroot and green pea at temperatures 85 and 90 °C, which were explained with logistic kinetic model rather than first order model (Fig. 3). The *D* value for firmness decreased with increase in temperature (Table 3). The *z* value for the firmness ranged from 32.56 to 55.71 °C. The activation energy for firmness was 13.22–34.68 kJ/mol, which is at par with the results reported in case of York cabbage (33.80 kJ/mol) (Jaiswal et al. 2012). The activation enthalpy and entropy were 0.18–0.28 and 8.46–28.71 kJ/mol K, respectively.

From these findings, it can be inferred that temperature and duration of blanching significantly reduced in bioactive components, antioxidant activity, colour and firmness of selected vegetables. Kinetic modeling revealed that, the changes in bioactive components and antioxidant activity could be better predicted by logistic models, on the other hand zero and first order models could predict the changes in colour and textural properties effectively. The thermal resistance time (*D*), *z* value, activation energy, activation enthalpy and entropy were calculated for all measured parameters and reported for selected vegetables. These finding would be useful in designing thermal processes and related calculations for these vegetables.

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