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RESEARCH PAPER

Evaluation of Rheological Characteristics of Various Blends of Soup Mixes by using Arrowroot Starch as Thickener

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ABSTRACT

The rheological properties of instant soup mixes from leafy vegetables with arrowroot starch at was determined at various shear rate 3.30, 5.50, 6.60, 11.0, 16.5, 27.5, 33.0, 55.0 (1/s) and at different concentrations (2:32%; 6:28%; 10:24%; 14:20% and 18:16%) of amaranthus: spinach were studied in the temperature ranges of 70, 80 and 900C. The leafy vegetable soups showed shear thinning (pseudoplastic) behaviour. The power law model was fitted to be adequate with R^2 0.950 and MSE 0.072 for arrowroot starch to fit the flow curves of instant soups from leafy vegetable (Amaranthus: Spinach). The consistency coefficient '*k*' increases from 0.075 to 3.695 with increase in temperature while the flow behaviour index '*n*' decreases from 0.960 to 0.292 with increase in temperature from 70 to 90°C. The power law and exponential functions were used to determine the consistency index '*k*' of leafy vegetables soup with arrowroot starch as a function of temperature and incorporated varied leafy vegetables (Amaranthus: Spinach) powder concentration. The effectiveness of developed combined models was judged by several statistical parameters. In general; exponential function fitted better for the effect of powder (Amaranthus: Spinach) concentration and combined effect of temperature was also fitted by the exponential function.

Keywords: Rheology, soup mix, viscosity, consistency index

Rheology is a branch of physics which deals with the deformation and flow of materials, both solids and fluids (Reiner, 1960). In the case of food materials, their rheological (deformation and flow) behavior is directly associated with their textural qualities. A viscosity-type test frequently used to evaluate the texture or rather consistency (resistance to deformation) of soft foods such as puddings, sauces, purees, soups and similar fluids (Finny, 1973). The viscosity of food is important for food processes and equipment, quality evaluation and control of food products, and understanding the structure of food materials (Isıklı and Karbaba, 2005).

The rheology of food materials is essential for numerous aspects of food science and technology, such as the standardized characterization of raw materials and innovative products, or for optimized conservation and industrial processing. Foods as composite materials combine the rheological responses of its individual components with additional effects originating from the interaction between all ingredients. Rheological properties vary from viscous fluids and elastic solids, defining the spectrum of possible material responses to applied stress, strain, or shear rate. The aim of

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rheological fluid characterization is to quantify the functional relationships between deformation, rate of deformation, and the resulting stresses acting in rheometric flow conditions (Fischer *et al.* 2009). In addition, the rheological properties of fluid foods are very important and primarily affect the sensory quality, and consequently, consumer preference. However, these properties can be influenced by some of the added ingredients (Yilmaz *et al.* 2010).

Food rheology focuses on the flow properties of individual food components, which might already exhibit a complex rheological response function, the flow of a composite food matrix, and the influence of processing on the food structure and its properties. For processed food the composition and the addition of ingredients to obtain a certain food quality and product performance requires profound rheological understanding of individual ingredients their relation to food processing, and their final perception (Fischer and Windhab, 2011).

Soups available in the market are generally manufactured by dry blending of ingredients in which food and ingredient powders and thickening agent forms the major part of the formulation. Rheological behaviour of soups are the important parameter which decide its acceptability by the consumers. Flow behaviour of soup is usually affected by constituents and the temperature of the soup (Chavan *et al.* 2015). A mathematical equation between apparent viscosity and shear rate has been described which can be related to the power-law model (Heikal and Hinnan, 1990): The power-law equation has been widely used in analysing viscosity, shear rate data.

In general, commercial instant food thickeners consist of modified starches and gums as their base materials and they are becoming more popular because of low cost, convenience, and easy preparation (Garcia *et al.* 2005). From a rheological perspective, soups are complex viscoelastic systems because of the interactions among starch, gum, and other ingredients, such as proteins.

The commercial production of soups depends on knowledge of the product's flow and textural behavior during and after processing. Therefore, it is important to understand the effects of and interactions between starches and food gums in the presence of any other ingredients that are critical to the functional properties of the food products (Sarker *et al.* 2013). Many researchers studied about the rheological characterization of the soup mixes, Ibanoglu and Ibanoglu, (1998) and (1999) studied the rheology of traditional turkish soup and tarhana soup. Chavan *et al.* 2015 reported about the rheology of tomato soup. Kim *et al.* 2014 reported the rheological properties of hot thickened soups. Amal *et al.* 2014 reported the rheological behavior of legume soup. Jaysinghe *et al.* 2015 reported the rheological behaviour of low cost seaweed based soups.

In the present investigation an attempt has been made to evaluate the rheological properties of experimental soups with different concentration of spinach and amaranthus powder and with thickener i.e. arrowroot starch at varied temperatures followed by rheological model fitting.

MATERIALS AND METHODS

Drying of vegetables

The vegetables i.e. spinach, amaranthus, onion, garlic and carrot was procured from local market and was dried at 45°C, 45°C, 55°C, 55°C and 55°C for 8.5 h, 10.5 h, 18 h, 15.5 h and 11.5 h respectively. The dried vegetables were grounded to 0.2 μ. The carrots were kept as such dried cubes.

Formulation of soup mixes

The dried powders of spinach, amaranthus, onion and garlic were used to formulate soup mixes with seasoning of cumin 0.66, coriander 0.66, black pepper 1.06, chilli 5, salt 7.33, onion 2, garlic 1.33, citric acid 0.33 and carrot 4.66 % respectively were considered as other ingredients i.e. 23 % remains same in all formulations. The formulations were made with arrowroot starch as a thikner the concentration of Amaranthus: Spinach was varied as 2:32, 6:28, 10:24, 14:20 and 18:16 (0.0625, 0.2142, 0.4166, 0.70, 1.125) respectively.

Table 1: Different formulations of soup mixes with arrowroot starch

Ingredients	T_1	T_2	T_3	T_4	T_5
Amaranthus (%)	2	6	10	14	18
Spinach (%)	32	28	24	20	16
*Other ingredients (%)	23	23	23	23	23
Arrowroot starch (%)	43	43	43	43	43

**cumin, coriander, black pepper, chilli, onion powder, garlic powder, salt, citric acid and carrot cubes.*

Sample preparation and shear rate shear stress data

The 15 g of soup mixes as per each treatment T_1 to T_5 was mixed with 150 ml of water as per procedure of Jaysinghe *et al.* 2016. The mixture was heated at 70, 80 and 90°C temperature in a water bath. The water bath along with sample was placed at bottom of viscometer. Shear rate – shear stress data was obtained using a Brookfield Viscometer RVDV II+ Pro (M/s Brookfield's Engineering Lab USA). About 150 ml of soup sample was filled into the 200 ml beaker and the disc spindle No. RV 06 attached to the viscometer which was immersed into the soup up to the marked portion. Torque was measured at 6, 10, 12, 20, 30, 50, 60 and 100 rpm rotor speed at temperature 70, 80 and 90°C conditions which is maintained in controlled temperature water bath (Make: Lab Hosp Instrument and Equipment Mfg. Co., Mumbai; Model: Labhosp Digital water bath). The spindle was rotated in the mixture soup till the constant dial reading was observed. The torque data was obtained at each rpm from dial reading obtained from the instrument was recorded. Each experiment was performed upto 3 times to get the replication and average reading was reported. The viscometer measures the torque during the rotation of the spindle in a fluid. The rpm of the spindle was converted into shear rates for the disc spindles reported earlier by the method described by Mitschka (1982) and Briggs and Steffe (1997). In this method the experimental data was converted to shear stress and shear rate. For the particular model of the viscometer used, the value of spring constant in calculation of shear rate was 1 obtained from the manual of the equipment.

Therotical Considerations

Power law model provides the mathematical rheological relationship between shear rate and shear stress which is used to verify the flow behaviour of leafy vegetable soup mixes is given as follows.

Mitschka (1982) has developed a simple technique to determine rheological parameters of power law fluids using a Brookfield viscometer (Briggs and Steffe, 1997).

$$\sigma = k.\gamma^n \qquad \ldots(1)$$

Where,

σ = Shear stress, P_a

k = Consistancy coefficient, $Pa.s^n$

γ = Shear rate, s^{-1}

n = Flow behavior index

Briggs and Steffe (1997) have improved the method by modeling the Mitschka data, the flow behavior index (n) and the consistency index (k) of power law fluids are obtained using the following procedure:

Shear stress (σ) of the soup sample was obtained using the spring torque (obtained by reading the instrument dial) and factors related with Brookfield model and spindle;

$$\sigma_a = k_{\alpha\sigma}\,(c^*\ dial\ reading) \qquad \ldots(2)$$

Where,

σ_a = Average shear stress, P_a

$k_{\alpha\sigma}$ = Shear stress conversion factor, P_a

= function of spindle No. RV 06 (2.35)

C = dimension less (spring constant i.e. 1)

The logarithm of shear stress is plotted versus the logarithm of rotational speed (N); the flow behavior index (n) is obtained as the slope of the graphic (Mitschka, 1982);

$$n = \frac{d\left(\log_{10}\sigma_a\right)}{d\left(\log_{10}N\right)} \quad \ldots(3)$$

Where,

σ_a = Average shear stress, P_a

N = Rotational speed, rpm

Average shear rate (γ) is then obtained by Eq. 4, empirically determined by Briggs and Steffe (1997):

$$\gamma_a = (0.263\ (n)^{-0.771})\ N \quad \ldots(4)$$

Where,

γ_a = Shear rate, (1/s)

n = Flow behaviour index

N = Rotational speed, rpm

1. Effect of temperature of soup on consistency index

Temperature dependency of soup on the consistency index, k of tarhana soup at a specified shear rate was successfully described by the Arrhenius model (Saravacos 1970; Rao *et al*. 1984). Linear regression analysis was applied to the logarithmic form of Eq. (5) in order to determine the parameters of relation i.e. k_0 ($Pa{\cdot}s^n$), Ea (kJ/mol)

$$k = k_0 \exp\left(\frac{E_a}{RT}\right) \quad \ldots(5)$$

Where,

k = Consistency index ($Pa\ s^n$)

k_0 = Constant for Arrhenius equations ($Pa{\cdot}s^n$)

E_a = Activation energy (kJ/mol)

R = Universal gas constant (kJ/mol/K) (8.135)

T = Absolute temperature (K)

2. Effect of concentration of soup on the consistency index

The variation of consistency index with concentration can be described by several different models (Rao *et al*. 1984; Ibarz *et al*. 1987). These are generally power law type and exponential type models as in the following:

$$k = k_1\left(C^{a_1}\right) \quad \ldots(6)$$

$$k = k_2 \exp\left(a_2 C\right) \quad \ldots(7)$$

Where,

k_1 = Constant for concentration effect ($Pa{\cdot}s^n$ $[\%]^{-a}1$)

k_2 = Constant for concentration effect ($Pa{\cdot}s^n$)

C = Concentration (%)

a_1 = Constant dimensionless

a_2 = Constant $(\%)^{-1}$

Linearized forms of Eqs. (6) and (7) were plotted, and corresponding model parameters i.e. k_1 ($Pa{\cdot}s^n$ $(\%)^{-a1}$), k_2 ($Pa{\cdot}s^n$), a_1, a_2 and R^2 were represents the values of the parameters of the power law and exponential relationships.

3. Effect of Concentration of leafy vegetables (Amaranthus: Spinach) in soup on activation Energy (E_a)

For a fixed temperature, activation energy for flow depends on the concentration. The variation of activation energy with concentration was modeled by using exponential and power law functions:

$$E_a = A_1\ (C^{B1}) \quad \ldots(8)$$

$$E_a = A_2 \exp\ (B_2C) \quad \ldots(9)$$

Where,

A_1 = Constant for a fixed temperature (kJ/mol/[%])

A_2 = Constant for a fixed temperature (kJ/mol)

B_1 = Constant for a fixed temperature (dimensionless)

B_2 = Constant for a fixed temperature $(\%)^{-1}$

The values of E_a and their respective concentrations were fitted to Eqs. (8) and (9) by the least square methods to obtain the estimates of the parameters of the models i.e., A_1, B_1 and R^2.

4. Combined Effect of Temperature and Concentration on the Consistency Index (*k*) of soup

For engineering applications, it is very useful to obtain a single equation describing the combined effect of temperature and concentration on the consistency index of soup. For this purpose, Eqs. (5) to (7) were combined to obtain the following model functions, which describe the combined effect of temperature and concentration: Multiple linear regression analysis were conducted on the linearized forms of Eqs. (10) and (11) to obtain their parameters i.e. k_3, k_4, D_1, D_2, E_a and R^2 (Yilmaz *et al.* 2010)

$$k = k_3 \exp(D_1 C + E_a/RT) \quad \ldots(10)$$

$$k = k_4 C^{D2} \exp(E_a/RT) \quad \ldots(11)$$

Where,

k_3 =Constant for combined effect $Pa{\cdot}s^n$

k_4= Constant for combined effect $Pa{\cdot}s^n$ $(\%)^{-D2}$

D_1 = Constant for combined effect $(\%)^{-1}$

D_2 = Constant for combined effect (dimensionless)

C = Concentration

T = Absolute temperature

RESULTS AND DISCUSSION

Rheological behaviour of leafy vegetable soup mixes with arrowroot starch.

Fig. 1, 2 and 3 indicates that the shear stress–shear rate relationship of leafy vegetable soups for various treatments T_1, T_2, T_3, T_4 and T_5 at 70, 80 and 90°C. As the shear rate (1/s) increases the shear stress (*Pa*) also increases. The shear rate verses shear stress data for leafy vegetable soup indicated the non-linear relationship, demonstrating that leafy vegetable soup using arrowroot starch samples exhibited a typical non-Newtonian shear-thinning flow behavior. The power law model was adequate for describing the flow behavior of leafy vegetable soup using arrowroot starch. The Table 2 shows the model parameters consistency coefficient (*k*) and flow behaviour index (*n*) for power law model and correlation coefficients were $R^2 \geq 0.950$ with MSE ≤ 0.039. The values of flow behaviour index (*n*) shown in Table 2 were found to be less than unity indicating that the soup samples were the pseudoplastic (shear thinning) fluids. Similarly by increasing shear rate the increasing shear rate behaviour were reported on the flow behaviors of some soups based on legumes, whey based tomato soup, turkish soup, tarhana soup, hot thickened soups (Amal *et al.* 2014; Chavan *et al.* 2015; Ibanoglu and Ibanoglu 1998; Ibanoglu and Ibanoglu 1999; Kim *et al.* 2014) respectively.

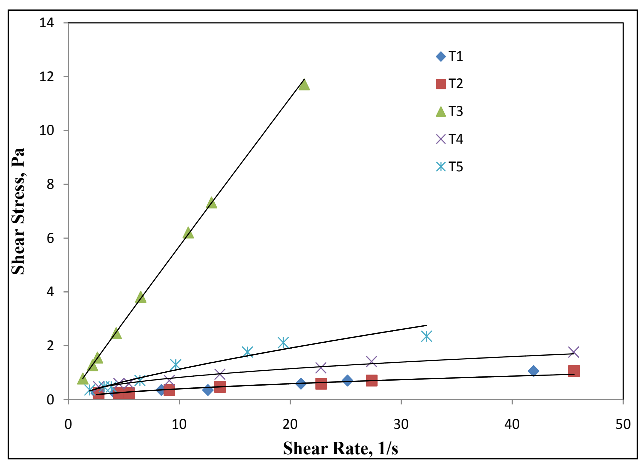

Fig. 1: Shear rate verses shear stress data showing the effect of treatments of leafy vegetables soup using arrowroot starch at 70°C

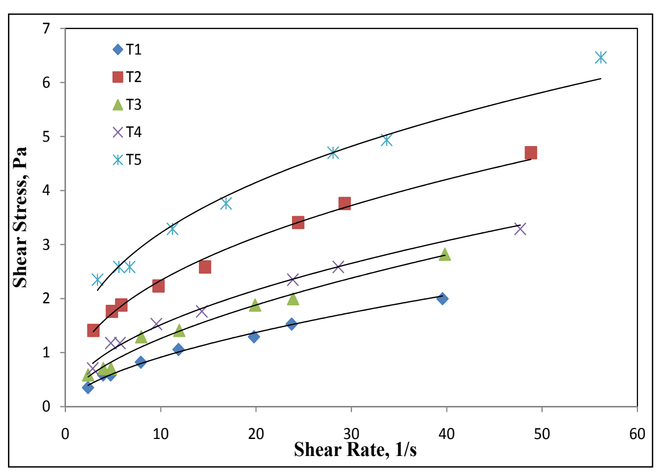

Fig. 2: Shear rate verses shear stress data showing the effect of treatments of leafy vegetables soup using arrowroot starch at 80°C

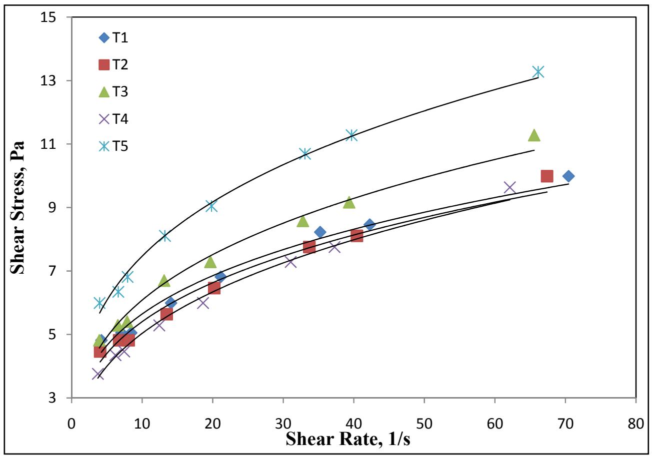

Fig. 3: Shear rate verses shear stress data showing the effect of treatments of leafy vegetables soup using arrowroot starch at 90°C

Table 2: Model parameters of power law equation at different treatments T_1 to T_5 (concentrations) and at varied temperature (70, 80 and 90°C) of instant soup using arrowroot starch

Temp.	Treatment	Cosistency coefficient (*k*), Pa.s^n	Flow behaviour index (*n*)	R^2	MSE
70°C	T_1	0.075	0.699	0.968	0.003
	T_2	0.083	0.657	0.982	0.002
	T_3	0.625	0.960	1.00	0.003
	T_4	0.251	0.509	0.989	0.003
	T_5	0.254	0.667	0.950	0.039
80°C	T_1	0.252	0.564	0.995	0.002
	T_2	0.840	0.441	0.995	0.007
	T_3	0.339	0.572	0.986	0.010
	T_4	0.493	0.492	0.994	0.005
	T_5	1.275	0.395	0.987	0.033
90°C	T_1	2.859	0.292	0.985	0.064
	T_2	2.588	0.314	0.984	0.072
	T_3	2.892	0.319	0.990	0.062
	T_4	2.236	0.348	0.993	0.032
	T_5	3.695	0.304	0.995	0.037

Table 2 shows the model parameters of power law model fitted for experimental data for treatment T_1, T_2, T_3, T_4 and T_5 at 70, 80 and 90°C respectively. The power law was best fitted for the experimental data with higher $R^2$0.950 values and MSE0.039 within all treatments and temperatures. Consistency index, *k*, is an indicator of the viscous nature of a food system which ranges from 0.075 to 3.695. Table 2 indicates that *k* changed with leafy vegetable powder concentration and increased with raising temperature from 70 to 90°C. Higher values of *k* showed a more viscous nature because of the increase in fluidity in leafy vegetable soup mixes using arrowroot starch. '*n*' values ranged from 0.292 to 0.960 under different conditions of concentration and temperature, indicating the pseudoplastic character of leafy vegetable soup mixes using arrowroot starch. The flow behaviour index n of soup mixes shows decreasing nature as temperature increases from 70 to 90°C.

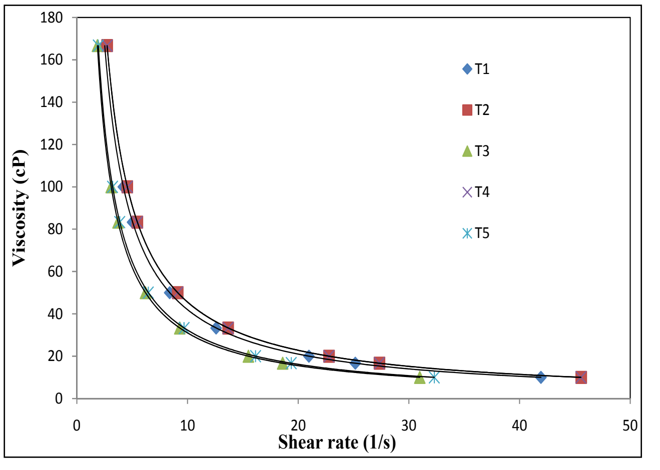

Fig. 4: Viscosity of soup mixes of different concentration using arrowroot starch at different shear rate and at 70°C

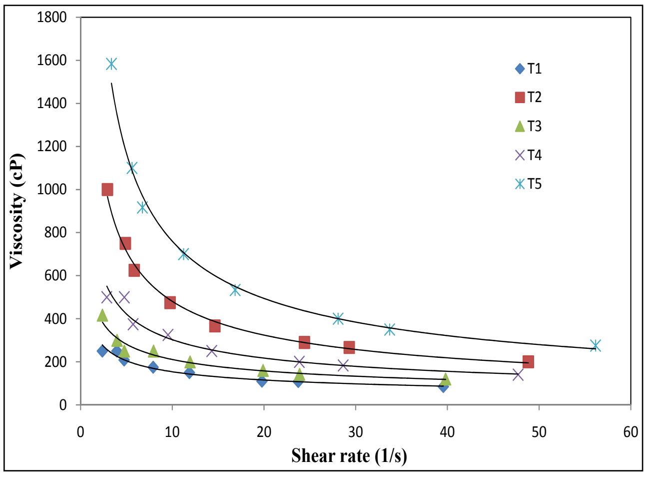

Fig. 5: Viscosity of soup mixes of different concentration using arrowroot starch at different shear rate and at 80°C

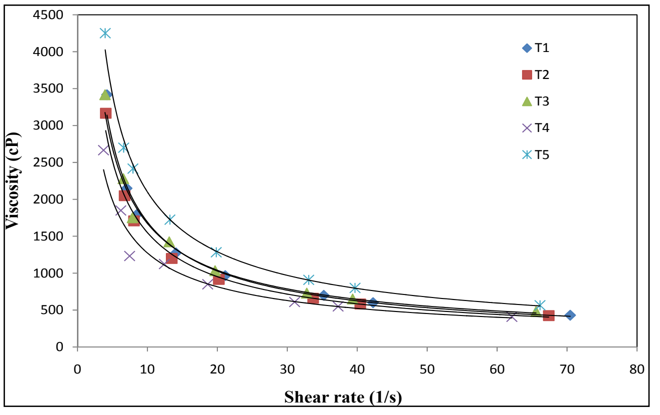

Fig. 6: Viscosity of soup mixes of different concentration using arrowroot starch at different shear rate and at 90°C

Fig. 4, 5 and 6 shows viscosity verses shear rate for soup prepared from the leafy vegetables for treatment T_1, T_2, T_3, T_4 and T_5 respectively at 70, 80 and 90⁰C temperature. The viscosity (cP) decreases with increasing shear rate(1/s) of leafy vegetable soups using arrowroot starch at different temperature indicated that increasing shear rate continuously disentangles the arrangements of long chained molecules, allowing to overcome the intermolecular resistance to flow (Holdsworth, 1971). The similar decreasing behaviour of viscosity with increasing shear rates were reported by Jaysinghe *et al.* 2016; Ibanoglu and Ibanoglu, 1999; Ibanoglu and Ibanoglu, 1998; Kaur and Das, 2014 for seaweed based soup, tarhana soup and turkish soup, whole barly flour suspension.

According to the power law model parameters the '*n*' values showed no consistent trend as influenced by concentration and temperature. Hassan and Hobani, 1998 reported that the flow behaviour index '*n*' was independent of the concentration and temperature while the consistency coefficient was more dependent on the temperature and concentration.

Effect of temperature on consistency coefficient (*k*)

Temperature dependency of consistency coefficient, '*k*' of soup mixes at different treatments T_1, T_2, T_3, T_4 and T_5 was described by arrhenius equation Eq.(5). Table 3 shows the magnitude of activation energy (E_a) varied from 16.335 to 24.881 kJ/mol with increasing concentration from 2:32 (0.0625) to 18:16 (1.125) (Amaranthus:Spinach). The highest activation energy 24.881 kJ/mol was observed at treatment T_1 concentration 2:32 (0.0625) while lowest 16.335 kJ/mol at 10:24 (0.4166) concentration of treatment T_2.

Table 3: The parameters of the arrhenius equation for temperature dependency (70, 80 and 90°C) of consistency index at different concentrations and temperatures

Treatments	Concentration (Amaranthus: Spinach)	k_0 (Pa.s^n)	E_a (kJ/mol)
T_1	2:32 (0.0625)	3270.392	24.881
T_2	6:28 (0.2142)	602.956	19.347
T_3	10:24 (0.4166)	235.086	16.335
T_4	14:20 (0.70)	402.562	18.420
T_5	16:18 (1.125)	2055.754	22.956

Effect of leafy vegetables (Amaranthus:Spinach) powder concentration on consistency coefficient (k)

The variation of consistency index with concentration can be described by power law type and exponential type models Eq. (6 and 7). Table 4 represents the values of the parameters of the power law and exponential relationships. Statistical analysis i.e. higher R^2 values indicated that the exponential model Eq. (7) seems to describe better the effect of Powder (Amaranthus:Spinach) concentration on the viscosity of soup samples. The k_2 rises with the temperature

Table 4: Effect of powder (Amaranthus:Spinach) concentration on the consistency index of soup at different temperatures

Temperature	Model:				Model:			
	k_1(Pa·s^n (%)$^{-a1}$)	a_1	R^2	MSE	k_2(Pa·s^n)	a_2	R^2	MSE
70°C	0.341	0.284	0.685	0.056	0.212	0.375	0.643	0.063
80°C	0.967	0.500	0.856	0.132	0.311	1.193	0.896	0.095
90°C	3.016	0.052	0.975	0.354	2.504	0.250	0.981	0.272

from 0.212 to 2.504 with $R^2 \geq 0.643$ and MSE ≥ 0.272 and a_2 increases from 0.375 to 1.193 with temperature 70°C to 80°C and again decreases from 1.193 to 0.250 with temperature 80°C to 90°C.

Effect of concentration on activation energy (E_a)

For a fixed temperature, activation energy for flow depends on the concentration. The variation of activation energy with powder (Amaranthus:Spinach) concentration was modeled by using exponential and power law equations Eq. (8 and 9). The Table 5 shows estimated parameters of these equations. The power law equation was better to describe the dependency of E_a on the powder (Amaranthus:Spinach) concentration with higher R^2 value.

Combined Effect of Temperature and Concentration on the Consistency Index (*k*)

For obtaining combined effect of temperature and concentration the, Eqs. (5) to (7) were combined; the Eq.10 and 11 describe the combined effect of temperature and concentration. Table 6 shows the combined effect of temperature and powder concentration (Amaranthus:Spinach) on the consistency index (*k*).

It can be seen that both models, Eqs. (10) and (11), (Table 6) adequately described the relationship; however, statistical analysis indicated that Eq. (10) better describes the combined effect of temperature and powder (Amaranthus:Spinach) concentration on the consistency index, *k*, of soup samples with higher R^2 value 0.624.

A multiple regression analysis on the consistency index (*k*) temperature–concentration data showed that the statistically fitted model of Eq. (10) could be proposed to analyze the apparent viscosity of leafy vegetable soup with arrowroot starch and can be used as a single model.

$$k = 100.91 \exp\left(0.473C + \left[\frac{13.484}{8.314T}\right]\right) \quad \ldots(12)$$

The pooled data for experimental consistency index, 'k'values for various concentration (T_1 to T_5) and at varied temperature (70, 80 and 90°C) versus those predicted by Eqs. (10) and (11), are represented in Fig. 7 which also indicates the adequacy of the developed models. The determination coefficient R^2 values for Eqs. (10) and (11) were 0.624 and 0.612, respectively. The figure indicated a good agreement between experimental values and therotical (predicted) values of k predicted by the models (Eqs. 10 and 11), similar results were observed by Yilmaz *et al*. 2010 for tarhana soup with whey concentrate.

Table 5: Effect of powder (Amaranthus:Spinach) concentration on the activation energy of flow

Power law function $E_a = A_1\left(C^{B1}\right)$					**Exponential function** $E_a = A_2 \exp\left(B_2 C\right)$				
A_1	B_1	R^2	MSE	χ^2	A_2	B_2	R^2	MSE	χ^2
18.910	-0.067	0.981	13.130	39.391	20.483	-0.009	0.977	16.048	48.143

Table 6: Combined effect of temperature and powder (Amaranthus:Spinach) concentration on the Consistency index (k)

Equation	**Parameters**			
$k = k_4 C^{D_2} \exp\left(\frac{E_a}{RT}\right)$	k_3(Pa·s^n) = 100.914	D_1 = 0.473	Ea (kJ/mol) = 13.484	R^2 = 0.624
$k = k_4 C^{D_2} \exp\left(\frac{E_a}{RT}\right)$	k_4(Pa·s^n(%)$^{-D2}$) =100.914	D_2 = -0.109	Ea (kJ/mol) = 12.402	R^2 = 0.612

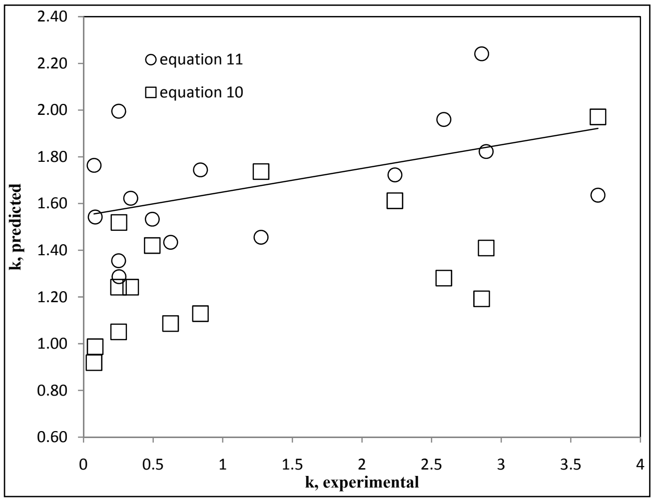

Fig. 7: Plot for experimental versus predicted consistency index, *k* of leafy vegetable soup with arrowroot starch

CONCLUSION

The rheological behaviour of instant leafy vegetable soup mixes was studied with varied concentration of amaranthus and spinach (2:32, 6:28, 10:24, 14:20 and 18:16) with arrowroot starch at varied temperature (70°C, 80°C and 90°C). The fluid behaves the non-Newtonian shear thinning behaviour. The power law model was best fitted for experimental data. The consistency coefficient k was increased with increase in temperature from 70 to 90°C. The flow behaviour index '*n*' was decreases with increase in temperature from 70 to 90°C. The power law and exponential functions are used to evaluate the effect of powder (Amaranthus:Spinach) concentration, temperature and combined effect of both concentration and temperature on leafy vegetable soups with arrowroot starch. The used functions had a good fit and would be useful for engineering applications in the processing of leafy vegetable soup with arrowroot starch. The combined effect of concentration and temperature was better described the Eq. 10 with higher R^2 value 0.624 which is useful in process design and quality control of leafy vegetable soup with arrowroot starch.

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