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Rheological studies on moringa leaves (*Moringa Oleifera*) purees

Jagamohan Meher, Bidyut Mazumdar, Neena Dixit, Seema Keshav and Amit Keshav*
Department of Chemical Engineering, National Institute of Technology, Raipur-492010, Chhattisgarh, India
dr.amitkeshav@gmail.com

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Abstract

During thermal handling of food items, it is more important to control the temperature history and resistance properties of the food. Commercial sterilization of the food is accomplished by putting the food items within the container and warm it. By the mechanism of heat transfer, the heat infiltration is obtained between food material and container. However, heat transfer through convection mechanism is uncommon in green leafy vegetables because of their non-Newtonian behavior. So a study on rheological properties as a function temperature and solid concentration of the puree is very important for design and development of the instrument. In our present research, rheological properties of the moringa puree as a function of temperature and frequency is done. Frequency sweep test was performed at 313K for both blanched and unblanched moringa puree. For both blanched and unblanched puree, the elastic modulus (G') and viscous modulus (G") shows an increasing trend with an increasing frequency and temperature. However, purees discovered higher values of G' as compared to G", which conclude that purees are showing weak gel behavior. Different rheological models are tried for its rheological properties, however Ostwald model fitted well. A non-Newtonian behavior with a decrease in viscosity and increase in shear rate was seen in this puree. And shear thinning behavior of purees is confirmed by plotting a graph between the shear rate and shear stress and it shows flow behavior index value (n)<1. Different Plot was drawn between shear rate and a viscosity at different solid concentration and temperature of purees. This data is helpful in design and development of thermal processing unit and for increasing the shelf life of the purees, which could use for our food-processing sector.

Keywords: Rheology, Purees, Temperature, Concentration, Viscosity.

Introduction

For the assurance of the rheological conduct and its derivatives, Moringa leaves have been the object of low review as a result of the restricted accessibility of new vegetable leaves in their locale and getting short time span of usability. In Moringaceae family, it is the most broadly developed species which is found most parts of India especially in sub-Himalayan tracts, it is also found sufficient amount in Afghanistan, Bangladesh, and Pakistan[1]. All the plant parts have been observed to be exceptionally helpful, particularly the leaf part, it can be utilized as forage, and option for the nourishment of newborn children and youngsters battling lack of healthy food[2]. M.Oleifera leaves contain considerable measures of vitamin (A, C, E), add up to phenols, proteins, copper, potassium, magnesium, manganese, calcium[3]. Also rich in noteworthy measure of fundamental amino corrosive alpha linoleic acid[4] likewise contain critical measure of phytonutrients, for example, carotenoids, ascorbic corrosive and tocopherols[5,6]. Yang R.Y. et al[7] reported that by modulating the expression of iron-responsive genes M.Oleifera leaves can supplement the iron deficiency. As indicated by Yang R.Y.[7], leaves are a great source of dietary cancer prevention agents and in view of previously mentioned wholesome advantages of leaves; the leaves utilized as functional ingredients in the food and associated industries.

In human history, so much literature is accessible in regards to green leafy vegetables that are utilized as a part of dishes and soup making. M. Oleifera leaves are utilized as a part of preparing salad, tea and in a blend with melon seed and spinach in varying proportion for making soup[8]. Despite the fact that moringa plant is broadly utilized still there are limited scientific studies exist to substantiate this claim.

Because of the inadequacy of processing and storage facility of M.Oleifera leaves, a substantial part of local produces is squandered. It is essential to protect these leaves, so sun-drying, salting, and maturation are ordinarily used to keep up food freshness when fresh food is not accessible. Expanded human advancement and development have postured for more prominent requests of better quality processed food both for fulfilling the nutritious advantages along with being economical. An imperative and most broadly utilized preservation method in the food business is the thermal handling of food items. Food sterility can be accomplished by interminable time temperature combination. Nonetheless, the duty of food process is to create an economically aseptic item as well as an item, which is wholesome, and retain nutritional and quality characteristics. For this, as a component of temperature and time, it is basic to concentrate the relative changes of nutritional and quality elements[9]. Nutrient and sensory qualities loss are negatively influenced by the components accelerating or hindering microbial degradation.

In the food industry, various products such as pastes, puree etc can be produced from the raw leaves and can also be sold directly to the consumers in fresh form. Hence, the study of puree rheology is very important and essentially required. However, the fluidic nature of puree does create some challenges in terms of flow, design, and handling in the commercial equipment. The real obstacle in the flow of pureed food during transportation is non-consistency in size; sometimes they totally stop the handling operation by hindering the valve leeway[10]. Moreover, the rheology of suspensions is impacted by an interior system which is created by the collaboration between the aqueous phase and solid particles[11]. So in the investigation of rheological properties of puree as a component of temperature, consistency in size is vital[12-13], shape, particle size[14-16] and total soluble solids[17].

The puree is a suspension of delicate unbalanced particles in a thick gel or serum[18], at rest, they are present in a disordered state and when shear stress is applied, the molecules or particles tend to adjust themselves towards the applied force. With the increase in stress, higher the ordination, and consequently, it lowers the viscosity. So, as the viscosity of leaf puree decreases with increasing shear stress, they are classified as pseudoplastic non-Newtonian fluids. This type of generic behavior was also previously seen[19]. The four available empirical models are used for rheological studies of non-Newtonian fluids by relating the data of shear rate with shear stress.

As puree of green leafy vegetables exhibits non-Newtonian characteristics, so it is difficult to predict the heat penetration via convection[20]. Because of this most of the parts of the container is overheated which cause puree deterioration. Till now there is no literature on moringa puree related to its rheological properties as a function of temperature and concentration. So present research mainly deal with the rheological properties of the puree as a function of temperature and its preservation treatment, and also on shelf life and thermal stability of chlorophyll pigments. So the present research led the industry to use it in the manufacturing process of purees and pastes. But different vegetable purees have different properties, so the results did not reach the same level of quality[21]. And the data can be used for design of thermal processing unit of food industries.

Materials and methods

Sample preparation: Vegetable leaves were bought from the nearby market and washed in running tap water, de-stemmed and transferred for experimentation within 2 h. Sample, if not used, were stored at 277K until use. The yield of leaves after de-steaming is 60-70%. Blanching process was chosen as important aspect of the experiment because, in one hand the vitality contribution because of the heat treatment could influence the structures of the leafy tissue; then again, inactivation of the compounds would maybe protect the structure so the color, viscosity, and texture of the pureed tissue could be analyzed all the more precisely. A known quantity of leaves was submerged in excess of water and subjected to blanching in the respective blanching media for 5 min Effectiveness and time of blanching was determined by peroxidase inactivity test. After blanching, the leaves were immediately cooled to room temperature (301K) by soaking in ice-cold water. The leaves were mechanically crushed into a puree utilizing a wet grinder (Prestige, India) at 298K for 15 min. It is then gone through a 14-work screen to acquire consistency. The puree is a blend of insoluble solid fiber particles and a serum of solvent solids in the arrangement.

The strategy for isolating the serum and fiber by centrifuge was evaluated as far as the span of centrifugation and the impact of the centrifugal force. Separation of serum and fiber is done till immersion is accomplished i.e. the amount of isolated molecule did not alter with centrifugation time. As the particles were hydrated by the portion of serum this was considered as vital. It was accounted for already that fiber weight is an imperative calculate terms of viscosity for tomato puree[14], and along these lines, the estimation states of this parameter were considered for rheology. To acquire samples with an extensive variety of solid fiber content, the puree sample had been centrifuged(MRC, London) at 1000 rpm for 30 min, the weight and volume of the aggregate specimen were noted and afterward, solid fiber (supernatant) were isolated from the serum. The serum was carefully poured out from the centrifuge tube and the tube inverted for 30 minutes. The solid fiber was weighed and the volume of the particles ascertained. After the separation, the puree with a range of solid fiber produced by reconstitution, by blending the fiber and serum to get five groups of the sample (36%, 40%, 46%, 52% and 58%). The diluted samples were enough blended utilizing a magnetic stirrer to accomplish uniform consistency for rheological investigation.

Physico-chemical properties: Chemical analysis to decide the proximate composition of the sample was done utilizing the standard methodology. moisture content was dictated via air drying, fat by Soxhlet extraction, carbohydrate computed by difference method, ass content by incineration, crude fiber by incineration after acid and base digestion (AOAC, 1990) and pH measured by a pH -meter (Systronics, Ahmedabad).

Pulp content determination: The Pulp contents of the moringa leave puree were determined in triplicate by centrifuging at 1000 rpm for 30 min at 298K. The Pulp content was expressed as the relation between the solid fiber weight (Ws) and the initial sample weight (Wsw)[22].

The pulp content of the sample was computed by utilizing equation,

$$\text{Pulp content (\%)} = \frac{W_S}{W_{SW}} \times 100 \quad (1)$$

Rheological measurements: The rheological examination of puree was measured utilizing the modular compact Rheometer (MCR-102 Anton Paar GmbH, Germany). The samples of puree (35 ml) were filled the container having the test volume of 40 ml. A stirred type four-bladed vane geometry ST22-4V-40 was mounted and correctly brought down into the sample cup by 10 mm from the surface level. What's more, the get together was interfaced to a microcomputer for control and information procurement and was utilized for rheological estimation. Leafy purees generally described as non-Newtonian liquids, due to their complex associations between the fiber and serum segments. For every test, the filled specimen glass (35ml) and spindle were temperatures equilibrated for around 10 min. At that point, the sample was subjected to three cycle shear with ramped from 1/s to 100/s, the steady shear rate at 100/s followed by decreasing the shear rate from 100/s to 1/s with fixed measuring point length for a period of 5min. The flow curves were developed and fitted with different models at a temperature of 303K. These temperature and shear rate had been selected because of their extensive use in the food industry[23]. Appropriate care was taken for each experimental run and during loading of fresh puree sample in a cylindrical cup of the Rheometer. So that we can avoid the sample from high shear rate and aging. And all the rheological estimations are performed in thrice using Rheo Plus software package for the accuracy of the results[24].

Selection of rheology models: Study on rheology is important for processing condition and for enhancing the product shelf life by its thermal studies[17]. However, heat addition during thermal studies causes tissue softening of the vegetable puree, due to which release of starch and lipids and so on take place from the cell wall. Which form a complex form of vegetable paste and puree. So due to its complex structure, it is difficult to predict the flow behavior but most purees exhibit non-Newtonian behavior. However, the correct reason behind this is still unknown, therefore non-Newtonian models are considered for the flow designs and heat stability studies. And the experimental data are fitted to different non-Newtonian rheological models, which are given below.

Ostwald-de-Waelle $$\tau = K(\gamma)^n \quad (2)$$

Herschel-Bulkley $$\tau^{0.5} = \tau_0 + K(\gamma)^n \quad (3)$$

Casson $$\tau^{0.5} = K_{OC} + K_c(\gamma)^{0.5} \quad (4)$$

Mizrahi and Berk $$\tau^{0.5} = K_{om} + K_m(\gamma)^n \quad (5)$$

Where: τ = Shear Stress (Pa), γ = Shear rate (s^{-1}), K = Consistency index (Pa.s), n = Behavior índex (dimensionless). Koc = Initial shear stress of the Casson model (Pa), Kc = Casson plastic viscosity (Pa.s), Kom = Shear stress of the Mizrahi and Berk model ($Pa^{0.5}$), τ_0 = Initial shear stress (Pa).

Results and discussion

Physio-chemical characteristics: The moisture content assumes a vital part in the growth and exercises of plants. Water is essential to the ingestion and transportation of nourishment to carry on photosynthesis, metabolism system of materials and the control of temperature. It is additionally essential for a large portion of the physiological responses in plant tissue and in its absence life does not exist[25]. The moisture content of the fresh moringa leaf was around 76% (wet basis), which dropped to 75% in the blanching and draining. The moisture content was not essentially changed after blanching or even subsequent to crushing since the moringa leaves are rich with water content, and the blanching was taken in a vast volume of water. No critical leaching of color pigments or nutrient was seen in the blanching media after removal of the specimen. The sample was a crush at room temperature, so there was no possibility of evaporation; the moisture content was stayed 75% (wet basis).

Protein as an essential nutrient for the growth and development was found to be 26.08% of fresh weight not changed significantly in leaf sample. The total carbohydrate and lipid content analyzed was 42.55 % and 2.25% respectively. Total dry matter content obtained was 22.05%. The total ash content determination was that of fresh leaf sample analyzed (7.2%). The high ash content is an indication of mineral contents conserved in the leaf materials and hence the reduction suggests a decline in overall mineral nutrients within the leaf tissues. Total carotenoid, chlorophyll a and b content established by analysis of the healthy leaf sample are 99, 43.20 and 49.5 µg/g respectively. Previous studies on analysis of moringa leave showed the following facts about chemical components[26]. They are; Water 5.9g, protein 27.2g, lipid 17.1g, total sugars 38.7g, fiber 19.7g, magnesium 0.37g, potassium 0.013g, calcium 2g, iron 0.028g, Pro-vitamin A 0.01g, vitamin C 0.017g per 100g of the edible leaf. Also, some studied revealed the nutritive value[27] of moringa leaves (protein 27.51 %, fat 2.23%, and carbohydrate 43.88%). Even though previous studies have focused on the chemical composition of the leaf in terms of antioxidant properties of Moringa leaves[28], and a systematic study on nutritional features of the leaves on invasion with rheological studies has not been reported. The values reported were within the range as reported with marginal variations. This deviation may be due to agro-climatic conditions, maturity level, processing and varietal differences etc.[29]

Blanching studies on moringa leaves: Blanching was performed in open containers. It is assumed that no significant change in moisture content and leaching of pigments happens during blanching. The assumption is in agreement with some of the other works in literature and by physical observation during our experimentation particularly for leaching of pigment. All the physical operations were carried out at room temperature and the assumption of no evaporation of the pigments validated. The best method of blanching was ascertained by determination of chlorophyll content of the blanched puree. Blanching was performed at a temperature of 353K. A color loss during blanching is affected by both the type of blanching media the heating media as well as the cooling media.

Table-1: Physio-chemical characteristics of moringa puree.

Parameters	Amount
Moisture (%)	76.25±2.21
Ph	4.05±0.57
Ash content (%)	7.2±0.5
Dry matter content (%)	22.05±1.05
Crude Fat content (%)	2.25 ± 0.37
Crude Protein (%)	26.08 ± 2.72
Carbohydrate (%)	42.55±0.88
Chlorophyll-A (µg/g)	99±1.03
Chlorophyll-B (µg/g)	43.20±0.65
Total Carotenoid (µg/g)	49.55±0.52

Viscoelastic behavior of the food material is determined by measuring G'' and G' value. Higher the value of G' (Elastic modulus) indicates less viscous the food material and vice versa. Similarly, a higher value of G''(Viscous modulus) recommends that the puree is thicker so that we can predict the crystallization, melting and gelation properties of the food materials. Frequency sweep tests were performed for both blanched and unblanched puree at a temperature 313K. With the increase in frequency from 0 to 30 Hz both G' and G'' value gradually increase in both blanched and unblanched purees. But G'' shows overshoot and damping of value which prevails rest of frequency. So the purees were found higher G' value as compared to G'', which means that puree showed more elastic behavior and weak gel behavior. Other purees like aloe vera suspension[30] and rocket puree[31] have also comparable with moringa puree. G' and G'' value decrease with increase in pressure aloe vera suspension.

At 313 K, contrasted with the unblanched sample, blanched sample have a 2-fold decrease in the G' value, which means unblanched sample has higher viscous properties. This happened in the case of blanched puree because of heat addition during blanching process. Heat addition destructs the cell wall structure of plant cells and leaching of different cell constituents like lipids, starch etc take place from the cell wall. Research are still now are going on to find out the correct reason behind this. At higher temperature, there was a vast increment in G' value in case of rocket leaf puree[31]. The reason behind this could be the release of starch trapped in the chloroplast of the cell[32]. Effect of blanching in the case of moringa purees on G' and G' are represented in Figure-3. And at temperature 313K, the Figure shows huge contrasts in G' value for both blanched and unblanched case.

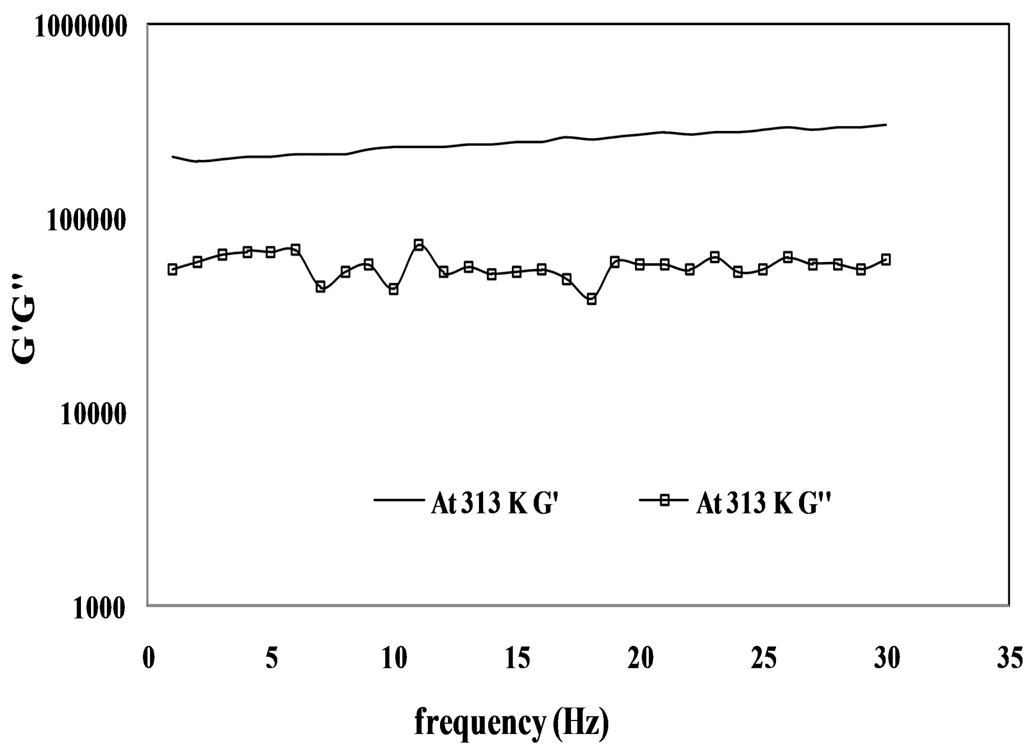

Figure-1: Frequency sweep tests for blanched puree at 313K.

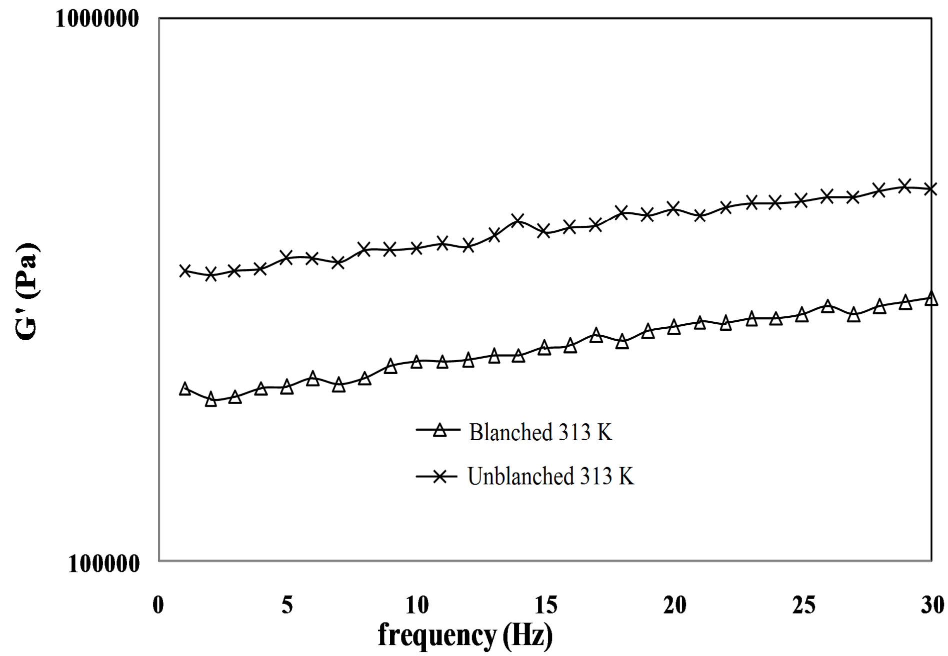

Figure-2: Frequency sweep tests for both blanched and unblanched puree at 313K.

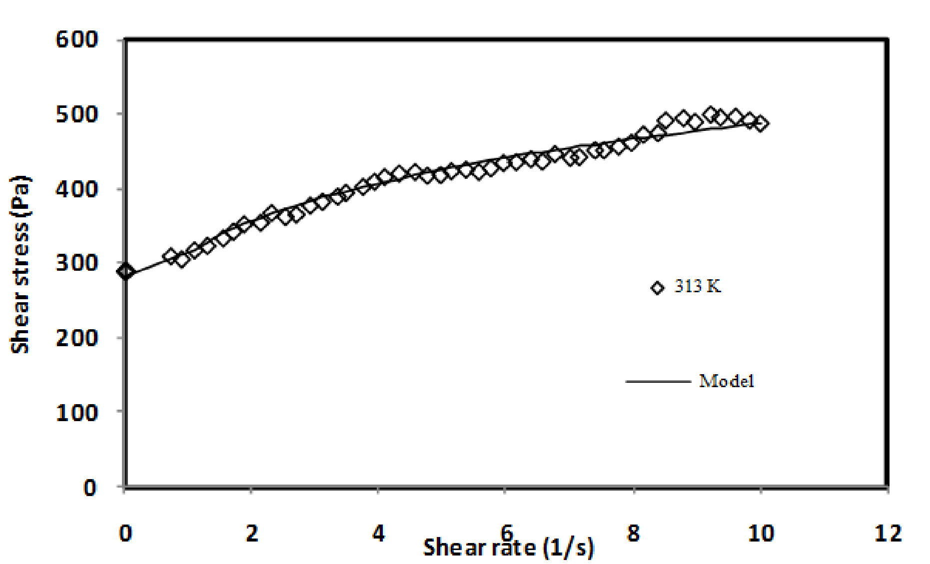

Figure-3: Ostwald fitted shear rate vs. shear stress graph of blanched puree at 313K.

Table-2: Rheological parameters of power law model.

Concentration (%)	K	n	R^2
36	0.0270	0.7442	1
40	0.8129	0.3605	1
46	1.8323	0.2294	0.998
52	4.6913	0.1216	1
58	9.2131	0.0866	0.99

Table-3: Rheological parameters of Herschel Buckley model.

Concentration (%)	K	n	Tau (τ)	R^2
36	0.02701	0.74417	-5.64719E-6	0.99
40	0.81855	0.35928	-0.00744	1
46	1.841	0.22884	-0.01025	1
52	4.72386	0.12096	-0.03383	0.997
58	1418.80226	7.22678E-4	-1409.87276	1

Table-4: Rheological parameters of Casson model,

Concentration (%)	K_{OC}	Tau (τ)	R^2
36	0.03089	0.18179	1
40	0.11321	3.46485	0.9998
46	0.10338	6.00517	1
52	0.09747	12.22714	1
58	0.11534	22.41739	0.999

Table-5: Rheological parameters of Mirazi Berk model.

Concentration (%)	K_{OM}	n	Tau (τ)	R^2
36	0.05402	0.74418	-7.07418E-6	1
40	1.63709	0.35928	-0.01487	1
46	3.682	0.22884	-0.0205	1
52	9.44774	0.12096	-0.06768	0.9998
58	3147.70532	6.51587E-4	3147.70532	0.999

Rheological properties: Comparison of selected rheological models: The rheological parameters of moringa puree were analyzed with solid % of 36, 40, 46, 52 and 58 at a temperature of 303K and compared the fits of all the four models. The most appropriated numerical models for describing the flow qualities of moringa purees was picked in perspective of the coefficient of determination(R^2), the presence of yield stress and overall bias factors gained during the fitting.

Although all models were well fitted but from the experimental data, it was observed that at temperatures of 303K Herschel-Buckley and Mizrahi- Berk fitted model showed negative values during the initial shear stress, which are having no physical meaning. Ostwald-de-Waelle fit satisfactorily at 303K and the coefficient of determination (R^2) value was found to be greater than 0.97. Therefore, in this case, power law model was more appropriate to describe the rheological behavior.The values of the flow behavior index (n) found for Ostwald-de-Waelle model were below the value of one (n <1) as the case of rocket leave and Aloe Vera puree having n values of 0.04-0.[13] and 0.16-0.25.[24] Respectively.

The values of consistency indexes, K and Kc determined by the power law and Casson models, decreased with the temperature during the study of clarified orange juice[33]. Moreover, the consistency indices K_h and K_m determined from the models of Herschel-Buckley and Mizrahi-Berk, respectively, did not show any trends with temperature. This is due to its negative values for the initial shear. So the most suitable model was obtained by observing the coefficient of determination (R^2) and being considered as the best model with the greatest value of R^2.

The graph of shear stress vs. strain rate obtained for the moringa puree in temperatures of 303K and their respective fits by the Ostwald-de-Waelle model showed in Figure-1.

It is observed that non-Newtonian behavior with slopes of flow curves decrease with an increment of shear rate, showing a decrement in viscosity with an increment of strain rate, and which confirming the pseudoplastic behavior of the moringa puree. Similar trends can also found in all other solid content purees.

Effect of temperature and solids content on viscosity: The effect of solids concentration on viscosity of puree at a temperature of 303K was studied. The viscosity of moringa puree at 100/s increased by about 0.40 Pa s as the dissolved solids content was increased from 34 to 58 % (Figure-5). The reason behind this is that at higher solid content causing a higher hindrance to the flow than the lower content due to its high viscosity.

From tests made prior to rheological measurements was found that the puree of above 58% solid content was unstable due to its high sedimentation rate, and its rheological behavior was not so good. However, the rheological measurements made at below 34% of solid content puree showed no adequate reliability to determine its flow behavior because of presented Taylor vortex, hence the concentrations of the puree (34% to 58%) used for rheological study at the constant ramp in shear rate from 1/s to 100/s. It showed an initial decrease of viscosity and afterward, it showed a constant value. The initial decrease of viscosity was attributed to an irreversible deflocculating. The viscosity-shear rate curves of different concentrated puree were similar and the behavior was shear thinning.

Viscosity decreased little when the shear rate increased and the flow became Newtonian. This is the characteristic of pseudoplastic fluids, which have been observed in our viscosity-shear rate diagrams.

For the designing of any pumping system for puree transportation from one place to another place, shear stress and viscosity of the purees play an important role. However processing temperature and concentration of the puree is also going to affect the flow property of the purees must not be neglected during design. For low-temperature concentration process, the thickness will change by a large margin before the desired concentration is reached. Which help in the outline and choice of pumps for liquid flowing in the whole viscosity ranges.

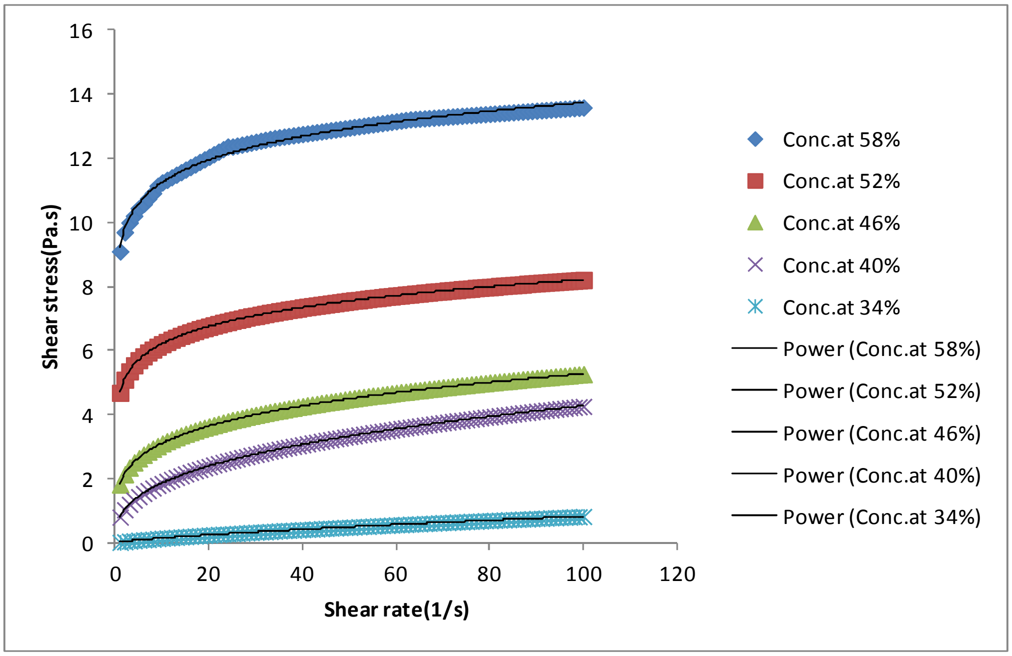

Figure-4: Power law fitted puree having different solid content at 303K temperatures.

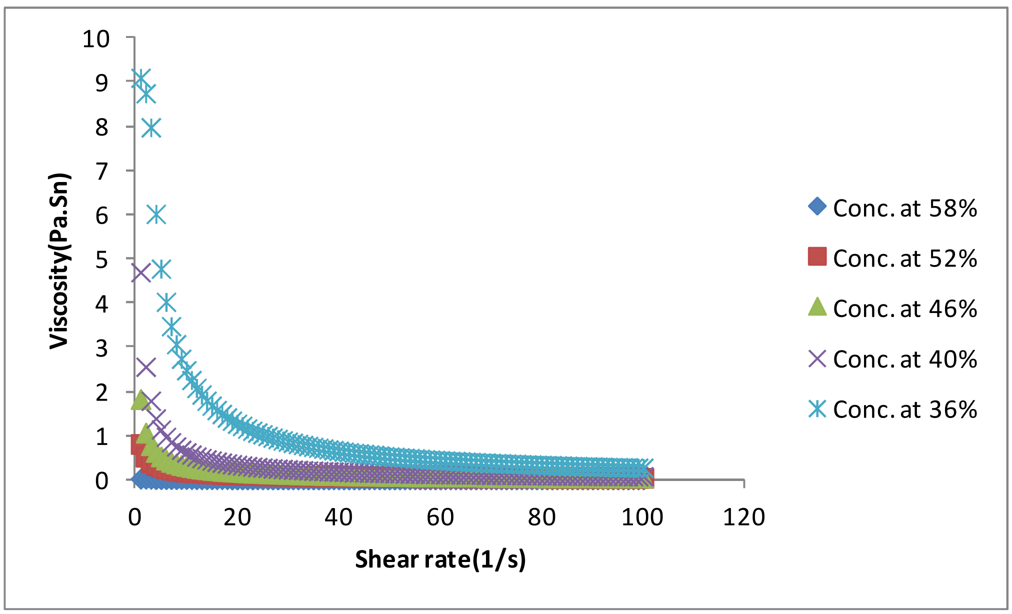

Figure-5: Viscosity and shear rate for various solid content purees at 303K temperatures.

Effect of flow behavior and consistency index on solid content of puree: The degree of pseudo-plasticity mainly depends on upon flow behavior index (n) and consistency index (K)**.** K value of puree decreases in different solid content in % (34, 40, 46, 52 and 58) at a temperature of 303K. However, in the present work, n value increases in all above the solid content of puree and the value are less than 1 which refers to shear thinning behavior but at a temperature of 303K, n value decreases with increase in solid content. The reason of shear thinning behavior is because of confounded communication of the particles in scattering with each other.

At lower solid concentration, molecules are separated from each other and move freely. With increase concentration, the molecules touch each other and form an entangled network because molecules force them to interpenetrate one another. Therefore, there is an increase of viscosity, which make the puree much steeper, and at the same time, the viscosity changes with shear rate. Fig. 4 demonstrates flow curves of shear stress various concentration purees with increasing shear rate. All the puree samples are showing non-thixotropic (i.e. time-independent) and shear thinning behavior, this type of behavior seen in apple[34] and others purees[21,35].

Rheological behavior of different concentrated puree with increasing temperature: The rheological parameters of moringa puree were analyzed and fitted to power law models. Noting that power law model was more appropriate to describe the rheological behavior of moringa puree in the ranges of solid content. The values of consistency indexes (K) determined by the power law during the studying of clarified orange juice[36], decreased with the temperature.

The graph of shear stress vs. strain rate obtained for the moringa puree with temperatures of 303K and their respective adjustment by the model of Ostwald-de-Waelle shown in Figure-4. The nonlinearity between shear stress and shear rate applied for shows a non-Newtonian behavior with slopes of flow curves decrease with increasing strain rate. Moreover, it appears a decrease in viscosity with increasing strain rate and confirming the pseudoplastic behavior of the moringa puree. Generally, a decreasing trend of viscosity due to increased intermolecular distances[37] is seen in the case of fruit juices and pulps[38]. Similar behaviors in his work on cranberry and concentrated juices were reported[39].

Conclusion

Studies on different blanching methods in view of the color preservation of moringa leave were presented. The rheology of blanched and unblanched puree is examined by frequency and temperature tests. Viscoelastic behavior of purees are determined by both G' and G" and its value was found an increase with an increase in the temperature and the frequency. However, G" value shows damping and overshoot in rest of the frequency range. The blanched sample has 2-fold diminish in the G' value contrasted with the unblanched test. Different concentration of solid purees (36-58%) are prepared and it shows that with an increase in concentration and shear rate there is a decrease in viscosity and afterward it showed a constant value at a temperature of 303K. Different non-Newtonian models are tried, however, Ostwald flow model fitted well for the above purees. The flow behavior (n) value of puree decreases from 0.7442 to 0.0866 and consistency index (K) was found to vary from 0.0270 to 9.2131 with an increase in solid concentration from 36-58% at a fixed temperature of 303K.

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