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Effects of stabilizers on rheological properties of Aloe vera (*Aloe barbadensis* Miller) gel

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ABSTRACT

The rheological properties of Aloe vera gel stabilized with different stabilizing agents *viz.,* phosphoric acid (0.1%, 0.30%, 0.50%), methyl paraben (0.25%, 0.50%, 1.0%), propyl paraben (0.25%, 0.50%, 1.0%), ascorbic acid (0.05%, 0.08%, 1.0%), citric acid (0.01%, 0.03%, 0.05%) and sodium benzoate (0.05%, 0.25%, 0.50%) was studied at constant temperature of 25°C using PVS Brookfield model Rheometer. The shear rate ranged between 8.52 to 34.06 s^{-1}. The results indicated that the stabilization of Aloe vera gel causes increase in viscosity and shear stress. The four rheological models *viz.,* Power law, Bingham, Casson and Herschel-Bulkley models were studied for rheogram fitness. The Power law model provided good fit with R^2 value varied from 0.968 to 0.998, P (0.015 to 0.067), RMSE (0.019 to 0.089), SSE (0.013 to 0.083) and $\div^2$ (0.019 to 0.054). The value of flow behavoiur index,' n' varied from 0.42 to 0.86 indicating Aloe vera gel is shear-thinning (Pseudoplastic) behavior.

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Key words : Aloe vera, Rheology, Shear stress, Stabilization, Viscosity

INTRODUCTION

Aloe barbadensis Miller is popularly known as Indian Aloe or Barbados Aloe is a perennial herb with fleshy leaves. The Aloe plants considered to be of *Liliaceae* and *Aloeaceae* family, which has numerous different species (Reynolds, 2004 and Danhof, 2006). Aloe vera is endemic to the Arabian Peninsula of Africa. The plant is xerophylous, being well adapted to dry land areas, and has tissue highly modified for water retention and storage. The gel of the plant has traditionally been employed by man for its content of substance known for healing, and other properties (Max, 1982). In recent years, it gained reputation in food industry as a major ingredient for many products for providing essential nutrients to human body. There are many industries now concentrated only on processing of Aloe vera and earning profit to a remarkable level. In addition due its therapeutic properties, it is used as a neutraceutical food. Aloe vera gel can also be potentially utilized as a coating material for enhancing shelf-life of table grapes and other fruits (Juan *et al.,* 2005; Walter and Patrick, 2005).

Aloe vera gel is mucilaginous jelly consisting of 98.5 per cent of water. Because of high moisture content, gel is rapidly oxidizes, decomposes and putrefies. Putrefaction of gel leads to the loss of many important constituents of gel, and make it useless for food purpose. Hence, proper shelf-life enhancing process is essential. Different researchers described different processing techniques of gel regarding its sterilization and stabilization, *i.e.*, cold process or heat treatment. However, the fundamental principle underlying these processing techniques remains almost same. Regardless of the quality of the plant, the best results are obtained, when leaves are processed immediately after harvesting. This is because the degradative decomposition of the gel matrix begins due to natural enzymatic reactions, as well as the growth of bacteria, due to the presence of oxygen.

Stabilization is a process involving neither heat nor

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chemical treatment given to Aloe vera gel to improve its shelf-life and consistency. It has been reported that stabilization can be achieved by the addition of preservatives *viz.,* sodium benzoate, potassium sorbate, citric acid, acetic acid, propyl paraben and methyl paraben (Rex, 2005 and Khambalkar *et al,* 2007).

The topic of the present research, rheological properties is one of the most widely used tool in processing industries. Aloe vera gel is highly viscous in nature because of high viscosity it poses problems in processing. The information on rheological properties of gel is very essential for its processing. By definition, rheology is the study of the deformation and flow of matter. Rheology of fluid foods provides good opportunities of study due to the biological nature of foods. Optimization of product development efforts, processing methodology and quality of food product require careful investigation of the rheological properties (Elif, 2003). Rheological data are essential for several areas in food industry *viz*., design of process equipment including heat exchangers, pipelines, mixers, extruder and pumps, determining the functions of ingredients during product development, intermediate or final product quality control, shelf-life testing and evaluation of food texture and sensory assessment (Pelegrine *et al*., 2002 and Peter *et al.,*2002).

Rheological measurements are quite relevant in the food industry as a tool for physical characterization of raw material prior to processing, for intermediate products during manufacturing, and for finished foods (Munizaga and Canovas, 2005). Viscosity is required in understanding the food texture as well as in designing transport system, heat exchanger equipment, deciding pump capacity, power requirement for mixing and in calculation of various dimensionless numbers. Viscosity data are useful for pressure drop calculations. Rheological parameters of Aloe vera gel play a vital role in processing industries, especially in powder making units for design of spray driers and pumping system (Caleb *et al*., 2007).

The aim of the present research was to study the effect of stabilizers on rheological properties of Aloe vera gel and to evaluate the fitness of different rheological models.

MATERIALS AND METHODS

Sample preparation:

Fresh whole Aloe vera (*Aloe barbadensis* Miller) leaves of 3-years old were collected from the Horticultural Garden, College of Agriculture, University of Agricultural Sciences, Raichur, Karnataka, India. The Homogenous leaves were selected according to the size, ripeness, colour and freshness. The hand filleting method was employed to extract the gel from Aloe vera leaves. The outer rind of the leaf was removed from the inner parenchyma layer with the help of a sharp stainless steel knife.

Stabilization of Aloe vera gel:

The prepared gel was heated to a temperature of 70°C for 5 minutes followed by addition of one of the stabilizer *viz.*, phosphoric acid (0.1%, 0.30%, 0.50%), methyl paraben (0.25%, 0.50%, 1.0%), propyl paraben (0.25%, 0.5%, 1.0%), ascorbic acid (0.05%, 0.08%, 1.0%), citric acid (0.01%, 0.03%, 0.05%) and sodium benzoate (0.05%, 0.25%, 0.5%) (Rex, 2005 and Khambalkar, 2007). The stabilized gel was properly stirred and flash cooled to a temperature of 5 to 7°C by keeping it in refrigerator (Rex, 2005).

Rheological properties:

The rheological measurements of the stabilized Aloe vera gel samples were carried out using a Rotational rheometer (Brookfield Engineering Laboratories, Inc., USA, Model PVS Rheometer) equipped with torque measuring head and rotating outer cylinder. A 'B1' geometry stator/bob was used as geometry set. All the experiments were carried out at 25°C temperature and shear rate in the range of 8.52 to 34.06 s^{-1}. The speed of the motor was selected within the range of 5 to 20 RPM (5, 10, 15 and 20). A temperature controlled bath was used to maintain the temperature of the sample constant at 25°C. For each test, a measured volume (23 ml) of sample was taken in the sample cup. The sample cup was carefully installed in the Rheometer by pushing it up squarely followed by tightening the knurled locking ring. Before conducting the experiment the Rheometer was calibrated to 0% of torque. The BEAVIS (Brookfield Engineering Advanced Viscometer Instrucition) test was used to set the different speed in a cycle at a constant time interval of 30 seconds. After checking all the parameters the instrument was made to run by rheovision software button. The rheological properties, such as viscosity (cP), shear rate (s^{-1}) and shear stress ($D.cm^{-2}$) were directly obtained from the rheovision software. Three replicates were made for rheological measurement.

Rheological models:

The models were selected on the basis of their effectiveness to describe the flow behavior of non-Newtonian fluids. The constant of the selected models were directly obtained by rheovision software. The fit quality of the proposed models on the experimental data was evaluated using linear regression coefficient (R^2), sum square error (SSE), root mean square error (RMSE), Chi-square (χ^2) and mean relative per cent deviation modulus (P). The statistical parameters were calculated employing the following equations.

$$SSS = \frac{1}{N}\sum_{i=1}^{N}(SSe - SSc)^2 \quad ...(1)$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(SSe - SSc)^2\right] \quad ...(2)$$

$$\chi^2 = \frac{\frac{1}{N}\sum_{i=1}^{N}(SSe - SSc)^2}{N - z} \quad ...(3)$$

$$P = \frac{100}{N}\sum_{i=1}^{N}\frac{|SSe - SSc|}{SSe} \quad ...(4)$$

Statistical analysis:

The data averaged into respective parameter requisites were subjected to suitable transformation. One-way analysis of variance was used to analyze the data. After proper analysis, data were accommodated in the tables as per the needs of objectives for interpretation of results. The microsoft excel (Microsoft corporation, USA) was used for analysis and interpretation. The standard procedure in agriculture statistics given by Gomez and Gomez (1976) was consulted throughout.

RESULTS AND DISCUSSION

The results obtained from the present investigation have been discussed in the following sub heads:

Effects of stabilizers on rheological behaviour of Aloe vera gel:

Viscosity and shear stress results obtained for Aloe vera gel treated with different stabilizers with different levels are presented in Fig. 1 to 6. The data clearly indicate that stabilization of Aloe vera gel causes increase in viscosity and shear stress of Aloe vera gel. The fresh gel (control) was recorded viscosity and shear stress of 1453.58 cP and 258.16 D.cm^{-2} The data in Fig.1 shows that among different treatments the phosphoric acid treatment recorded highest viscosity at level III (0.5%) (9166.97 cP) followed by propyl paraben, methyl paraben, sodium benzoate, ascorbic acid, citric acid and which significantly differed over other levels. This might be due to its strong stabilizing effects on gel because of this reason phosphoric acid treatment is mainly used in jelly, jam and cheese to improve its thickness (Dybing and Smith, 1998). The increase in viscosity may due to increased concentration of gel because of stabilization. Campanella *et al.* (1994) also reported that the viscosity increased with increase in concentration. The reason may be due to decrease in pH value.Sun *et al.* (2006) reported the decrease in pH enhanced the intermolecular association resulting in increased viscosity of wheat gliadins. The observations also indicate that among different stabilizers citric acid treatment recorded low viscosity. At level II (0.03%) recorded (3162.62 cP) which was at par with level III (0.05%) (3146.21 cP) and significantly differed over level I (0.01%) (3128.72 cP) and control (1453.58 cP). This might to be due to low stabilizing effect of citric acid.

Effects of shear rate on rheology of Aloe vera gel:

The effect of shear rate on rheological properties Aloe vera gels (both control and stabilized gels) were studied in shear rate range of 8.52 to 34.06 s^{-1} (Fig. 1 to 6). It is observed that viscosity of both control and stabilized gels decreased as a function of ascending shear rate. Fig. 1 to 6 indicate that the Aloe vera gel exhibited shear thinning behavoiur. Similar results were reported by Ali (1994) for pomegranate juice, Dak *et al.* (2006) for totapuri mango Juice and Mohammad *et al.* (2006) for date syrup and sesame paste blend. The relationship between viscosity and shear rate is depicted in Fig. 7 to 11. It shows that at all treatments (including control), the viscosity decreased as a result of increased shear rate. The major constituents of Aloe vera gel are water and polysaccharides. The fall in viscosity with increasing shear rate can be explained by the structural breakdown of the gel due to the hydrodynamic forces generated and increased alignment of these constituent molecules (Alparslan and Hayta, 2002). Shearing causes progressive deformation and disruption of fibres, resulting in less resistance to flow. In other words, shear induces an irreversible and permanent damage affecting the molecular structure of gel, namely fibre, fat and polysaccharide. Sopade and Filibus, 1995; Singh *et al.*, 2003 reported similar results on oil droplet of milk mixture. Shear induced structural breakdown related to oil droplet deflocculation had also been reported for egg-yolk stabilized emulsions by Moros, *et al.* (2002).

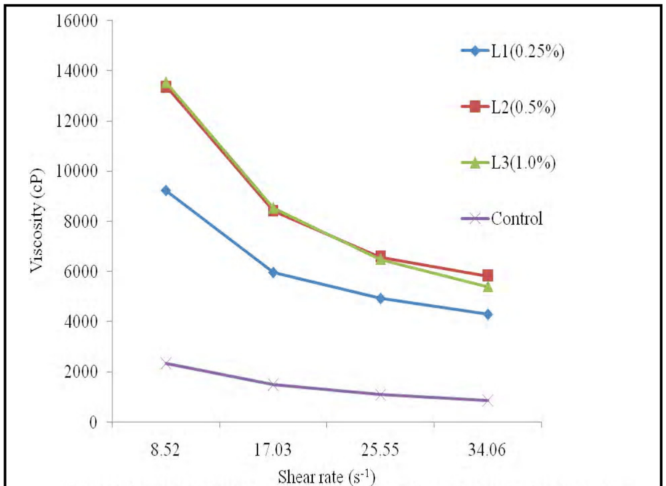

Fig. 1 : Viscosity-shear rate relationship in propyl paraben treated Aloe vera gel

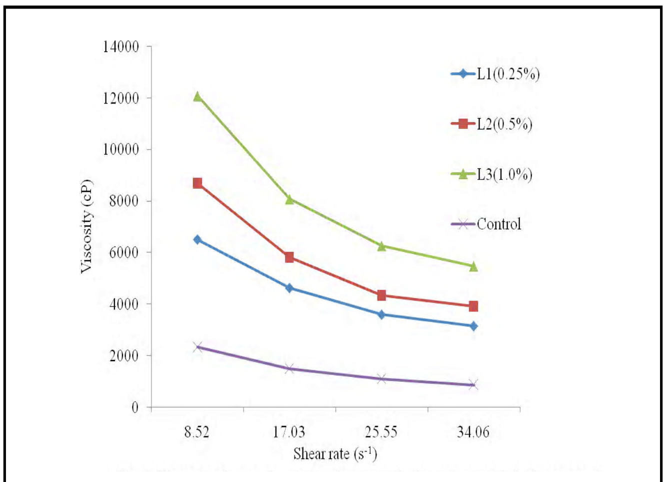

Fig. 2 : Viscosity-shear rate relationship in methyl paraben treated Aloe vera gel

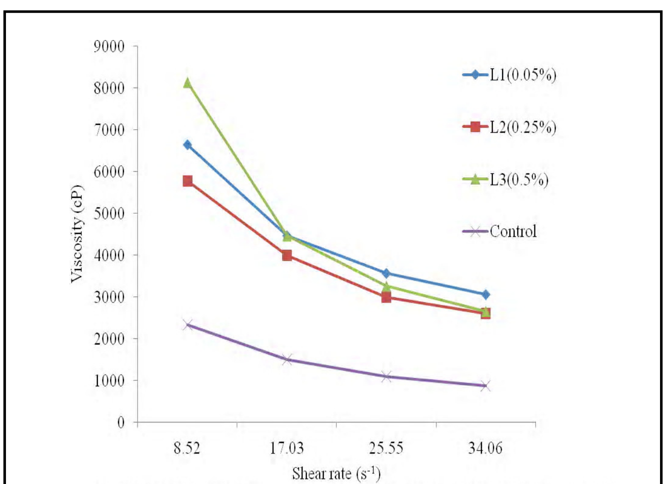

Fig. 3 : Viscosity-shear rate relationship in sodium benzoate treated Aloe vera gel

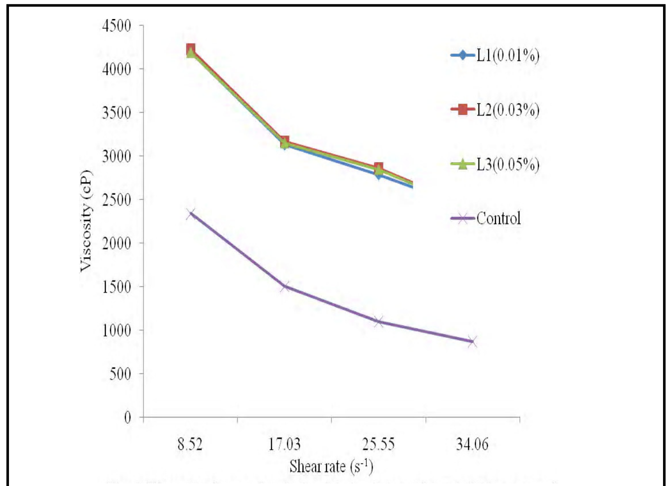

Fig. 4 : Viscosity-shear rate relationship in citric acid treated Aloe vera gel

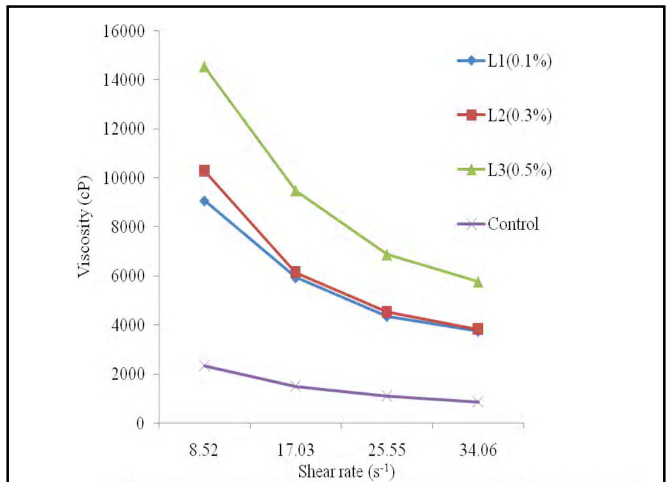

Fig. 5 : Viscosity-shear rate relationship in phosphoric acid treated Aloe vera gel

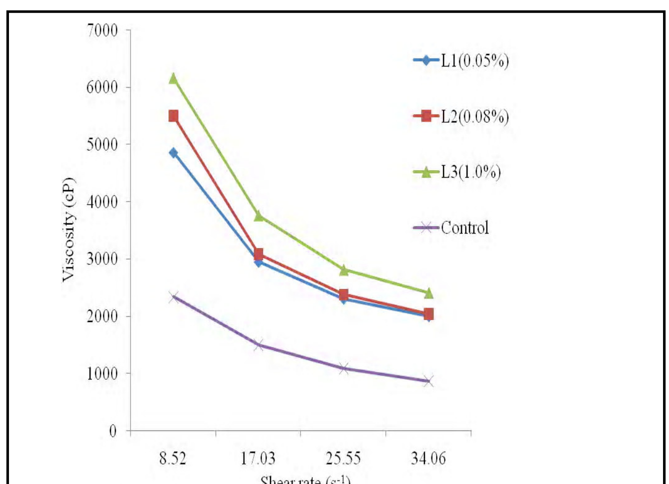

Fig. 6 : Viscosity-shear rate relationship in ascorbic acid treated Aloe vera gel

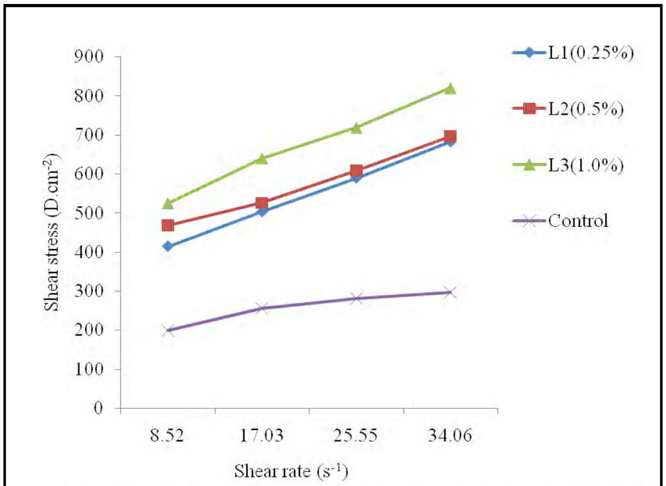

Fig. 7 : Shear stress-shear rate relationship in propyl paraben treated Aloe vera gel

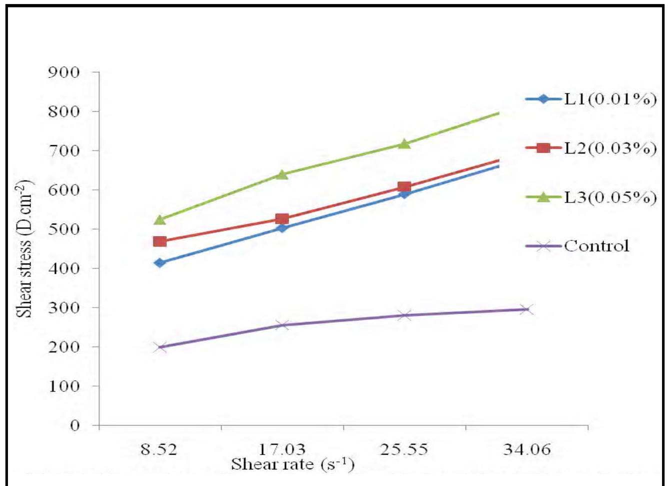

Fig. 10 : Shear stress-shear rate relationship in citric acid treated Aloe vera gel

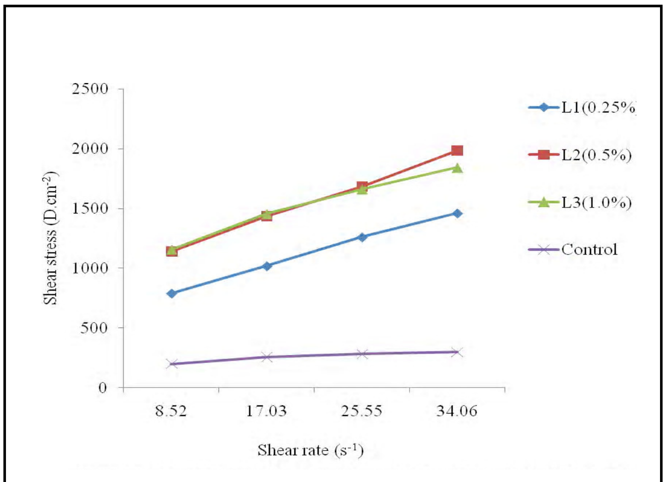

Fig. 8 : Shear stress-shear rate relationship in methyl paraben treated Aloe vera gel

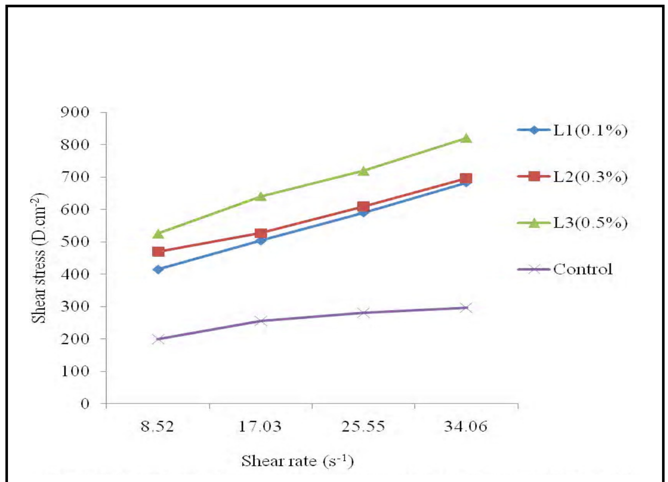

Fig. 11 : Shear stress-shear rate relationship in phopshoric acid treated Aloe vera gel

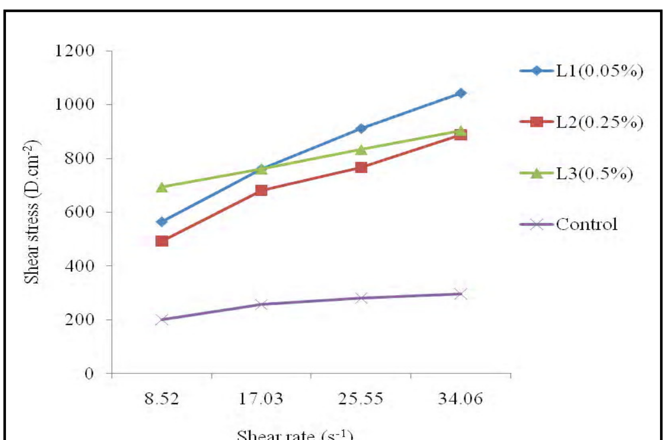

Fig. 9 : Shear stress-shear rate relationship in sodium benzoate treated Aloe vera gel

The flow behavior of Aloe vera gel is in agreement with Alparslan and Hayta (2002). They reported that tahin/ pekmez blends having pekmez concentration of 2-6 per cent (w/w) behaved as shear thinning foodstuff at the temperature of 30°C. According to their results, the flow behavior index (n) was in the range of 0.43 to 0.58, while the consistency coefficient (K), varied from 9100 to 87200 cP. Dak *et al.* (2006) also reported similar results on mango juice. In the present study, however, the values for flow behavior index appeared to be higher (0.41 to 0.86), 'K' varied from 9678 to 16320 cP, resulting less deviation from the Newtonian behavoiur.

Rheological model:

The rheograms results were analysed for flow behavoiur by employing different rheological models *viz.*, Power, Casson, Bingham and Herschel-Bulkley. At all treatments and different levels, experimental results of the variation of shear stress with shear rate were found to be indicating a shear thinning non-Newtonian behavior. Fig. 7 to 11 show the rheograms of gel at different treatments and concentrations. The Power-law model successfully described the relationship between shear stress and shear rate followed by Bingham but not with Casson and Herschel-Bulkley model. Similar result was reported by Ramaswamy *et al.* (1991) for stirred yogurt.

Power-law model appeared to be suitable for describing the flow behavior of Aloe vera gel as proved by the level of coefficient of determination (R^2) which gave values ranging from 0.973 to 0.998 (R^2>0.85), the mean per cent relative deviation modulus (P) (0.015 to 0.067), sum of square error (SSE) (0.013 to 0.083), chi-square (χ^2) (0.019 to 0.054) and root mean square (RMSE) (0.019 to 0.089). The consistency coefficient (K), flow behavoiur index (n) values obtained by fitting the shear rate versus viscosity to the Power model (equation 3.10) and these values ranged from 9678 to 16320 cP. It was also observed that the increase in concentration of stabilizers resulted in increased consistency index and decreased flow behavoiur index. The values of flow behavior index, n, varied between 0.41 and 0.86 (Dimensionless) indicating shear-thinning (pseudoplastic) behavior since figures were smaller than unity (n<1). The degree of pseudoplasticity can be measured by the flow behavior index (n) which is a measure of deviation from Newtonian. As 'n' increases, pseudo plasticity decreases.

Conclusion:

The results of the present study showed that the viscosity and shear stress of fresh Aloe vera gel was 1453.58 cP and 258.16 D.cm^{-2}, whereas, for stabilized gel, the viscosity varied from 3033.02 to 9166.97 cP and shear stress varied from 547.53 D.cm^{-2} to 1642.75 D.cm^{-2}. Among different treatments studied, phosphoric acid treatment of 0.5% recorded the highest viscosity (9166.97 cP) and ascorbic acid treatment 0.05% recorded the lowest viscosity (3033.02 cP). At constant temperature, an increase in shear rate resulted in decreased viscosity for all samples of Aloe vera gel indicating that the Aloe vera gel was a shear thinning fluid. Among different rheological models *viz.*, Power law, Casson, Bingham and Herschel-Bulkley models, the shear stress versus shear rate data were well described by Power law model with consistency index K, varying from 9678 to 15876 (cP), flow index n, varying from 0.41 to 0.86 which indicated that the Aloe vera gel was a non-Newtonian, shear thinning (pseudo plastic) fluid.

Nomenclature:

cP-centipoise, D.cm^{-2}-dyne per centimeter square, N-number of data points, P-mean relative per cent deviation modulus, RMSE-root mean square error, SSE-sum square error, SSe-experimental shear stress (D.cm^{-2}), SSc-calculated shear stress (D.cm^{-2}), z-number of constants, (χ^2) -chi-square

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