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Rheology of *Aloe barbadensis* Miller: A naturally available material of high therapeutic and nutrient value for food applications

V.N. Lad, Z.V.P. Murthy *

Department of Chemical Engineering, Sardar Vallabhbhai National Institute of Technology, Surat 395 007, Gujarat, India

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ABSTRACT

Due to the potential applications of *Aloe barbadensis* Miller (Aloe vera) in cosmetics, pharmaceutical and food products, the study of its rheology is important. Recently, many commercial food-product producers have boosted up the usage of Aloe vera gel or juice in one form or the other due to its nutrient ingredients. The present study reports the rheological characteristics of native Aloe gel and juice under dynamic and steady shear. The damping of the elastic moduli and viscous moduli at various temperatures for the Aloe gel under oscillatory shear tests have been reported, for the first time, which were observed due to the presence of weak, fibrous and random structure of polysaccharides in it. The moduli for gel increased with increasing temperature and that for juice decreased with temperature. Prior to attaining the plateau region after certain shear rate, Aloe vera gel and juice exhibited shear thinning behavior. The flow behavior index for Aloe gel samples was found to be 0.1 in the shear thinning region.

1. Introduction

Aloe barbadensis Miller (Aloe vera) is a member of the Aloaceae (formerly a member of Liliaceae) plant family (Ozsoy et al., 2009). It is being cultivated in many parts of the world, and also being used as an ayurvedic medicine or as an ingredient of many ayurvedic medicines in India since long (Sudha et al., 2011). *Aloe barbadensis* Miller is a shrubby tropical or subtropical plant having succulent and stilted cord shaped green leaves (Pugh et al., 2001). Many cultures in the world including Japan, China, Greece, Egypt, etc. have also used the gel obtained from the leaves of *Aloe barbadensis* Miller as a traditional medicine due to its anti-oxidant and anti-viral effects for wound healing, skin disorder as well as for skin burn (Marshall, 1990; Chithra et al., 1998; Pugh et al., 2001; Biswas and Mukherjee, 2003; Chandan et al., 2007). Recently, many commercial food-product producers, and confectioners have initiated the use of Aloe vera in their productions. Further, Aloe vera juice is also being marketed nowadays as a source of nutrient supplement and even as a medicament.

The leaves of Aloe vera are formed by a thick epidermis (skin). The skin surface is hydrophobic because it is covered with cuticles surrounding the mesophyll (Femenia et al., 1999). It contains chlorenchyma cells and thinner walled cells forming the parenchyma (filet). The transparent mucilaginous gel present in the parenchyma cells is known as Aloe vera gel. Vogler and Ernst (1999) have presented a review pointing out the effects of various constituents of Aloe vera gel. Aloe vera gel contains highly nutritious bio-active constituents including anthraquinones, alkaloids, enzymes, glycoproteins, vitamins and polysaccharides along with mucilaginous polysaccharides which are the major responsible constituents required for effective treatment for skin care as well as other therapeutic and cosmetic applications (Choi and Chung, 2003; Duansak et al., 2003; Eshun and He, 2004; Ni et al., 2004; Talmadge et al., 2004; Moghaddasi and Verma, 2011). Hu et al. (2003) and Wu et al. (2006) have found that the polysaccharides present in Aloe vera gel have anti oxidant effects. West and Zhu (2003) have found that the gradual delivery of Aloe vera gel to the dry – wrinkled skin helps in improving skin integrity and reducing wrinkle. Glucomannan, mannan, galactan, pectic substances and other polysaccharides have also been found in the Aloe vera gel (Segal et al., 1968; Waller et al., 1978; Mandal and Das, 1980a,b; Femenia et al., 1999; Chun-hui et al., 2007). The composition of the typical gels has been presented in the literature (Pierce, 1983; Femenia et al., 1999; Vogler and Ernst, 1999; Hu et al., 2003).

Despite many studies on Aloe vera gel leading to investigate its constituents and their functionality, there is a lack of information on rheological behavior of the same. Having many pharmaceutical, therapeutic and food applications reported in the literature for *Aloe barbadensis* Miller gel, it is very much important to know its rheological properties which can help for modification of the processing conditions in order to have products of better quality. Nindo et al. (2010) have reported shear stress – shear rate relationships for

* Corresponding author. Tel.: +91 261 2201641/2201648; fax: +91 261 2227334.
E-mail addresses: vnl@ched.svnit.ac.in (V.N. Lad), zvpm@ched.svnit.ac.in, zvpm2000@yahoo.com (Z.V.P. Murthy).

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aloe solutions prepared from freeze-dried, spray-dried, refractance window-dried aloe along with native aloe solution containing 15% (w/w) Aloe solids in water. Yaron et al. (1992) studied the stabilization effect of red microalgae and xanthan gum for enhancing the shelf life of Aloe vera gel. Understanding the rheology of the gel and the liquid present in its structure is indeed necessary, not only to design the commercial scale mixers or homogenizers but also to provide quantitative and qualitative means for development of suitable end product with desired consistency, mouth feeling and sensory effects. A detailed knowledge of the rheological properties of this natural material is crucial for many applications in various industrial processing including in pharmaceutical, cosmetics and food industries. The present work deals with the rheological characteristics of *Aloe barbadensis* Miller gel and juice under dynamic and steady shear with stress controlled and strain controlled rheometer. The microstructure, loss modulus, elastic modulus and complex viscosity of the Aloe vera gel and juice have been evaluated at various temperatures.

2. Materials and methods

2.1. Preparation of samples of Aloe vera gel and juice

Fresh and matured leaves of *Aloe barbadensis* Miller plant were used to recover Aloe vera gel. The leaves, cut from about 10 cm away from its lower end, and the epidermis were removed carefully to avoid damage to the natural structure of the gel. This gel was used for rheological experiments. The amount of water content in the gel was found to be 99.37% and that of the dry solid matter was 0.63%.

To prepare the samples of Aloe vera juice, the gel was scrapped from the leaves and the scrapped material was collected in a glass beaker. The material was centrifuged under the centrifugal acceleration of 5000*g* (where *g* is the acceleration due to gravity) at 27 ± 2 °C temperature in a high speed research centrifuge (Bio-Lab Instruments Mfg. Co., Mumbai, India) for 15 min. The supernatant fluid was used as Aloe vera juice for the analysis.

2.2. Evaluation of rheological characteristics

The rheological tests on oscillatory and rotational modes were performed on the Physica MCR-301 Rheometer (Anton Paar GmbH, Graz, Austria). The parallel plate geometry of 25 mm diameter with a gap setting of 4 mm was used for testing of the gel. Standard concentric cylinders (coaxial) geometry was used for the analysis of juice. The dynamic viscoelastic functions measured in terms of storage modulus (elastic modulus) G' and loss modulus (viscous modulus) G'' at three temperatures 15, 30 and 45 °C. The temperature was controlled by the Peltier heating element. Liquid nitrogen was used to maintain low temperature. The settings of the instrument were checked during the starting of all analytical tests. The experiments were repeated once to assure the observations free from any manual or instrumental error. Care was taken to avoid the loss of water from the samples by covering the free surface of the samples with a thin layer of silicon oil. Care was also taken to avoid the effects of sample loading by performing the gap setting very slowly to avoid high shear rates during sample loading. The samples were scrupulously placed on the test geometry using a spatula and then rotor was slowly lowered using a motorized system until the sample was in intimate contact with the sensor. To avoid the effects of aging, fresh samples were used for each experimental run for rheological measurements. The samples were allowed to reach to thermal equilibrium by providing rest time of 2 min at the test temperatures prior to the start of each test which also ensures the stress-relaxation of the sample (if any), observed during loading. The same protocol was followed for each experimental run.

For strain sweep tests, the samples were exposed to increase strain at constant frequency of 1 rad/s. The strain sweeps were performed at 15, 30 and 45 °C. This test allows determination of the linear viscoelastic regime of the sample. For frequency sweep tests, the samples were exposed to a frequency scan at a constant strain of 0.05% and in the range of 0.1–10 Hz frequency in the field of linear viscoelasticity at various temperatures. The data of rheological measurements were analyzed using the RheoPlus/32 V3.21 software of Anton Paar GmbH.

2.3. Determination of polysaccharides

The epidermis of the Aloe vera leaves was separated from the mucilaginous gel. The gel and juice samples were prepared as described earlier. Aliquots (2 mL) were used for polysaccharide determination. Sulphuric acid (95.5%, specific gravity = 1.84) and phenol (laboratory reagent grade) were purchased from Finar Chemicals, Mumbai, India. Deionised water (Elix® Millipore, India) having pH 6.1 ± 0.2, and conductivity 1.0 μS/cm was used as per the requirement throughout the determination of polysaccharides. Phenol–sulphuric acid method was used for the determination of polysaccharides as described by Dubois et al. (1956), using glucose as a standard. Analysis was done in quadruplicate to avoid any contamination error and for better conformity of the results and average value was used for the evaluation.

2.4. Optical microscopy

Optical microscopy was used to visualize the structural changes of the samples due to shear. Microscopic examination of Aloe vera gel and juice samples were done using an optical microscope (Labovision, Ambala Cantt, India), equipped with a digital camera. At least four microscopic images were captured for each test sample just before the test and also immediately after the test, and representative micrographs have been presented.

2.5. Statistical analysis

The replicates of all the experimental data were analyzed for measuring the mean and standard deviation using Micosoft Excel software. The significance difference was defined at $p < 0.05$ with 95% level of confidence.

3. Results and discussion

3.1. Frequency sweep test for Aloe vera gel

The results of dynamic frequency sweep tests are presented in Fig. 1 for Aloe vera gel. In frequency sweep tests, the storage moduli and loss moduli were increased with temperature. Huang et al. (2009) have observed such kind of increase of moduli with temperature for colloidal rod-like particles. Overall trend of increase of the storage modulus and loss modulus at higher frequencies has also been observed by Savary et al. (2008) for their rheological study on polysaccharide–starch composite gels.

As presented in Fig. 1, the loss moduli G'' curves show appreciable damping with frequency. Further, the degree of over-shoot and damping increased with increasing temperature. Storage moduli G' curves also exhibited damping but the damping was not remarkable at 15 °C. The storage modulus curve did not show damping at 15 °C. At all the temperatures under the rheological experimentation conditions, the material exhibited ‘solid like’ response which is clear by comparing the corresponding storage modulus and loss