PHYSICO-CHEMICAL AND RHEOLOGICAL PROPERTIES OF JUICES OF SOME EXOTIC FRUITS IN AN AGROFORESTRY SYSTEM AT DIFFERENT MATURITY STAGES

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Abstract

Knowledge of the rheological properties of food products is important for design and process evaluation, process control and consumer's acceptability of a product. The physico-chemical and rheological behavior of Orange, Pineapple and Grape juices, some common agroforestry fruit species were studied considering each fruit at four different stages of maturity viz: unripe, fairly ripe, fully ripe and overripe stages, so as to determine the flow behavior they exhibit, the pH level and the amount of sugar concentration present. The results obtained indicated that the apparent viscosity decreases with increase in shear rate for the samples. The viscosity values ranged between 0.0493 – 1.5513 Pas, pH values between 3.12 - 4.17, and the sugar concentration between 4.5 – 18^{o}Brix respectively. The unripe fruit juices of Orange, Pineapple and Grape have pH values of 3.36, 4.17 and 3.12 respectively, which were all acidic. Orange and Grape juice showed pseudoplastic behavior while Pineapple juice at its overripe stage showed a viscoplastic behavior.

Keywords: Rheology, Viscosity, Maturity Stages, Flow Behavior, Shear Stress and Shear Rate.

Introduction

Viscosity is usually considered an important physical property related to the quality of food products. Viscometric data are also essential for the design evaluation of food processing equipment such as pumps, piping, heat exchangers, evaporators, sterilizers' filters and mixtures. Several important factors needed to be taken into consideration in the design of food processing plants in order to assure the quality of the end products. One of them is rheology, which concerns the flow behaviour of the products. The measurement, adaptation and application of viscometry data, which concerns the design calculations of processing equipment is also studied.
Rheology originates from the Greek word *rheos* meaning to flow. Rheology is applicable to all types of materials, from gases to solids. The science of rheology is young, only about 70 years of age, but its history is very old. In the book of Judges in the Old Testament prophetess Deborah declared "The Mountains flowed before the Lord..." Translated into rheological terms by Professor M. Reiner, this expression means everything flows if you just wait long enough, a statement that is certainly applicable to rheology. It was also described by the Greek philosopher Heraclitus as "panta rei" - *everything flows*. Professor Reiner, together with Professor E. Bingham, was the founder of the science of rheology in the mid-20s. (Reiner, 1964).

In the dairy industry there are cream and cultured milk products whose characteristics can be partially or completely spoiled if their flow behaviour is not understood. In the prepared food industry there are desert products often containing starch based additives, soups and sauces containing particles and tomato products that require certain considerations regarding choice and design of equipment.

The viscosity of fluid foods is an important parameter of their structure behavior. It determines to a great extent the overall mouth-feel and influences the intensity of flavor. Therefore, for many years, the viscosity of liquid foods has been of interest to researchers and industrialists. Correlation between sensory and instrumental values of texture parameters can be used for industrial quality control to keep the sensory viscosity within a range assuring good consumer acceptance.

The fruit juice industry has become one of the world's biggest agribusinesses. The flow behaviour of fluid foods (FF) is essential for the design and evaluation of food processing equipment such as piping, evaporators, sterilizers and heat exchangers. Study of the rheological behaviour of FF is of particular interest in quality control, consumer acceptability, and engineering calculations related to the processing and handling of FF Moreira, (2005); Chin et al., (2009). With regard to these engineering calculations, knowledge of the applicable flow models is important for design of flow systems (Rao and Anantheswaran, 1982).

According to Zuritz et al., (2005), the juices and nectars physical properties, such as density, viscosity, specific heat and coefficient of thermal expansion, are affected by their solid content and their temperature. For this reason, it is necessary to know the physical properties values, as a function of the temperature and the solids content, during the manufacture process, not just to obtain an excellent quality, but also to develop a data base, that is essential for optimizing the installation design and the transformation process itself.

Processing of the juice from small fruit is a complex operation with many variables that influence the final product quality. A good knowledge of the flow behaviour of the juice is essential to understand and improve the technologies for different kinds of juices, that is, clear, cloudy or nectar Sanchez et Al., (2009). Rheology has implication on processing equipment design, product development, storage and transportation of juice.

This is, therefore, necessary to establish an analytical approach to the chemistry of the fruit juice preservation in order to specify properties of juice at different storage and distribution conditions. The objective of this work is to determine the physico-chemical and rheological properties of the three selected fruit juices at four (4) different maturity stages.

Materials and Methods

Materials

Selected fruits of were obtained from a farm in Ilara-Mokin area in Ondo state, Nigeria. The fruits are:

a. Sweet Orange fruit (*Citrus sinesis*)
b. Pineapple fruit (*Ananas comosus* L.) and;
c. Grape fruit (*Citrus paradisi)*

Four different maturity stages of the fruits were used; these are unripe, fairly ripe, fully ripe and over ripe stages. The materials used for this work are: various Fruit Juices, clean bowls, measuring cylinder, calibrated blender, Plug for socket, NDJ-5S digital viscometer, sterilized knife, pH meter, refractometer, sieve, white sieving cloth, plastic bottles, labels, clean white hand gloves

Methodology

All the fruits were washed with clean water so as to remove any adhering substances, sliced and hand peeled using sterilized knife so as to avoid any contamination. The bark of the fruits was carefully peeled off to enhance easy extraction of the fruit pulp or paste and the juice which was used for the experiment.

Juice Extraction

For each of the four maturity stages for each fruit types e.g. peeled unripe fruit, they were put together inside one bowl after which their seeds were removed.A calibrated liquefier Osterizer blender machine with 10 speeds was used to blend the fruits together for about 15 minutes to enhance homogenization. This Osterizer blender is a multi-speed appliance which operates on a wide range of speeds from very slow to very fast. This range of speeds makes food preparation easy, interesting and also saves time because it processes foods in seconds.

Each of the unripe, fairly ripe, fully ripe and over ripe fruit of Oranges, Pineapples and Grapes were put into different bowls. The actual juice extraction was done using a white clean sieving cloth and washed after each process of extraction for each of the fruits at the different maturity stages in order to avoid dilution of those fruit juices. The sieving cloth was pressed together manually to obtain the juice content from the fruit paste already blended. The samples were poured inside labeled plastic bottles and then taken to the laboratory for necessary analysis.

Determination of the Physico-chemical and Rheological Parameters

A PH5-3C pH meter with combined electrode was used to measure the pH level of the fruit juices at different maturity stages. The pH of a solution measures the hydrogen ion concentration in that solution. A small change in pH represents a large change in hydrogen ion concentration. For example, the hydrogen ion concentration of lemon juice (pH of 2.3) is 63 times greater than that of tomato juice (pH of 4.1), and 50,000 times greater than that of water (pH of 7.0).

The sugar concentration (^{o}Brix) and the refractive index were for each sample at the four (4) stages of maturity using the analogue Bellingham + Stanley Limited Refractometer No A 81015 at 20^{o}C

The rheological analyses of the fruit juices were carried out using a digital display viscometer (Model: NDJ-5S). This instrument adopts micro computer technology, range (rotor number and speed) can be set and the data determined by sensor can be processed conveniently, and the rotor number, speed, viscosity etc. can be displayed clearly on LCD. The instrument was designed and manufactured with 4 rotors (1#, 2#, 3#, 4#) and 4 different velocities (6 rpm, 12 rpm, 30 rpm, and 60 rpm), enabling it to measure any viscosity value in the given range.

For the purpose of this work, a small portion of about 16.0ml of the samples of the fruit juices were used for each experiment so as to bring the sample level to the immersion groove on the spindle shaft using spindle 1#.The analyses were carried out at room temperature in duplicate varying the velocity (rpm-revolution per minute) i.e. at 6, 12, 30 and 60rpm using spindle factors 100,200,500 and 1000 respectively as obtained from the viscometer operation manual and within which 48 measurements of apparent viscosity (Pa.s), shear stress (Pa), and shear rate (s^{-1}) were obtained respectively as shown in equations 3.1-3.3 respectively

The apparent viscosity values and shear rate were obtained by multiplying dial reading and rpm by appropriate factors (supplied by the Viscometer manufacturer).

Apparent viscosity =

$$\text{Dial reading} \times \frac{Spindle\ factor}{Speed\ (N)\ in\ rpm} \qquad (1)$$

Shear rate =
Speed (N) in rpm X factor (0.22) ....(2)

Also, the Shear stress in Pascal (Pa) was obtained thus;
Shear stress =
Apparent viscosity X Shear rate ....(3)

The pH level and the sugar concentration were then determined and analyzed. Also, the relationship between the shear stress (Pa) and the shear rate (per sec) of the fruit juices as well as their variations of apparent viscosity (ηa) with shear rate (per sec) at different maturity stages were determined and analyzed.

Statistical Analysis

Analyses were carried out on the obtainable data and analyzed using Microsoft Excel after which graphs of pH levels, sugar concentration, refractive index, flow curves and viscosity curves of Orange, Pineapple and Grape juices were plotted and used to determine the pH levels, sugar concentration and flow behaviour of the juices, respectively.

Results and Discussion

The pH values of the fruit juices across the different maturity stages were presented in table 1 and they show a slightly acidic behavior for all. The pH values for the unripe and fairly riped fruit juices were more of stronger acid than those of fully riped fruit juices that were of weaker acid. This also makes the fully ripe safer for consumption. The sugar content of the products were shown to be high across the maturity stage with pineapple showing the highest for all as seen in table 2. The refractive index was presented in table 4 for all the juice samples at the different maturity stages.

Table 1: pH values of the fruit juices at different maturity stages

Samples	Unripe	Fairly ripe	Fully ripe	Overripe
Orange juice	3.36	3.35	4.02	3.39
Pineapple juice	4.17	3.47	3.81	3.92
Grape juice	3.12	3.16	3.24	3.21

Table 2: Sugar content of the fruit juices in (°Brix) at different maturity stages

Samples	Unripe	Fairly ripe	Fully ripe	Over-ripe
Orange juice	6	4.5	6	5
Pineapple juice	7	11.5	18	6.5
Grape juice	6.7	6	7	5.5

Table 3: Refractive indices of the fruit juices in (°Brix) at different maturity stages

Samples	Unripe	Fairly ripe	Fully ripe	Over-ripe
Orange juice	1.341	1.339	1.342	1.341
Pineapple juice	1.340	1.349	1.354	1.342
Grape juice	1.3415	1.342	1.343	1.34

From table 4, the shear stress values ranged between 0.1848 – 8.7395 Pa and it has important effect on the mouth feel, consistency and other rheological properties of the fruit juice. Low viscosity and consistency has good effect in the mouth. As the shear rate increases, the shear stress for all the juice also increase across the maturity stages for all the fruits.

Table 4: Relationship between shear stress and shear rate at different maturity stages**.**

Speed (rpm)	6	12	30	60
Shear rate (s-1)	1.32	2.64	6.6	13.2
SS for Fairly ripe Orange Juice	0.26367	0.23984	0.4119	0.93907
SS for Fully ripe Orange Juice	0.14626	0.24776	0.48483	1.00661
SS for Overripe Orange Juice	0.1892	0.18484	0.32621	0.9097
SS for Unripe Pineapple Juice	0.35629	0.51579	0.65192	1.57234
SS for Fairly ripe Pineapple Juice	0.18946	0.4134	0.56771	1.5048
SS for Fully ripe Pineapple Juice	0.20827	0.47036	0.80812	2.20539
SS for Overripe Pineapple Juice	2.04776	2.6026	6.5065	8.7395
SS for Unripe Grape Juice	0.26019	0.25883	0.37362	0.78628
SS for Fairly ripe Grape Juice	0.35156	0.27933	0.53928	1.2001
SS for Fully ripe Grape Juice	0.34848	0.45085	0.82341	1.31219
SS for Overripe Grape Juice	0.2043	0.22048	0.4037	0.99165

Table 5: Relationship between apparent viscosity of the three juices at different maturity stages

Speed (rpm)	6	12	30	60
Shear rate (s^{-1})	1.32	2.64	6.6	13.2
AV for Unripe Orange Juice	0.16801	0.09307	0.07222	0.07476
AV for Fairly ripe Orange Juice	0.19975	0.09085	0.06241	0.07114
AV for Fully ripe Orange Juice	0.1108	0.09385	0.07346	0.07626
AV for Overripe Orange Juice	0.14333	0.07002	0.04943	0.06892
AV for Unripe Pineapple Juice	0.26992	0.19538	0.09878	0.11912
AV for Fairly ripe Pineapple Juice	0.14353	0.15659	0.08602	0.114
AV for Fully ripe Pineapple Juice	0.15778	0.17817	0.12244	0.16708
AV for Overripe Pineapple Juice	1.55133	0.98583	0.98583	0.66208
AV for Unripe Grape Juice	0.19712	0.09804	0.05661	0.05957
AV for Fairly ripe Grape Juice	0.26633	0.10581	0.08171	0.09092
AV for Fully ripe Grape Juice	0.264	0.17078	0.12476	0.09941
AV for Overripe Grape Juice	0.15478	0.08352	0.06117	0.07513

From table 5, the apparent viscosity values ranged between 0.0493 - 1.5513 Pa.s. It reduces as the shera rate value increases. This was observed for all the fruits across the maturity stages.

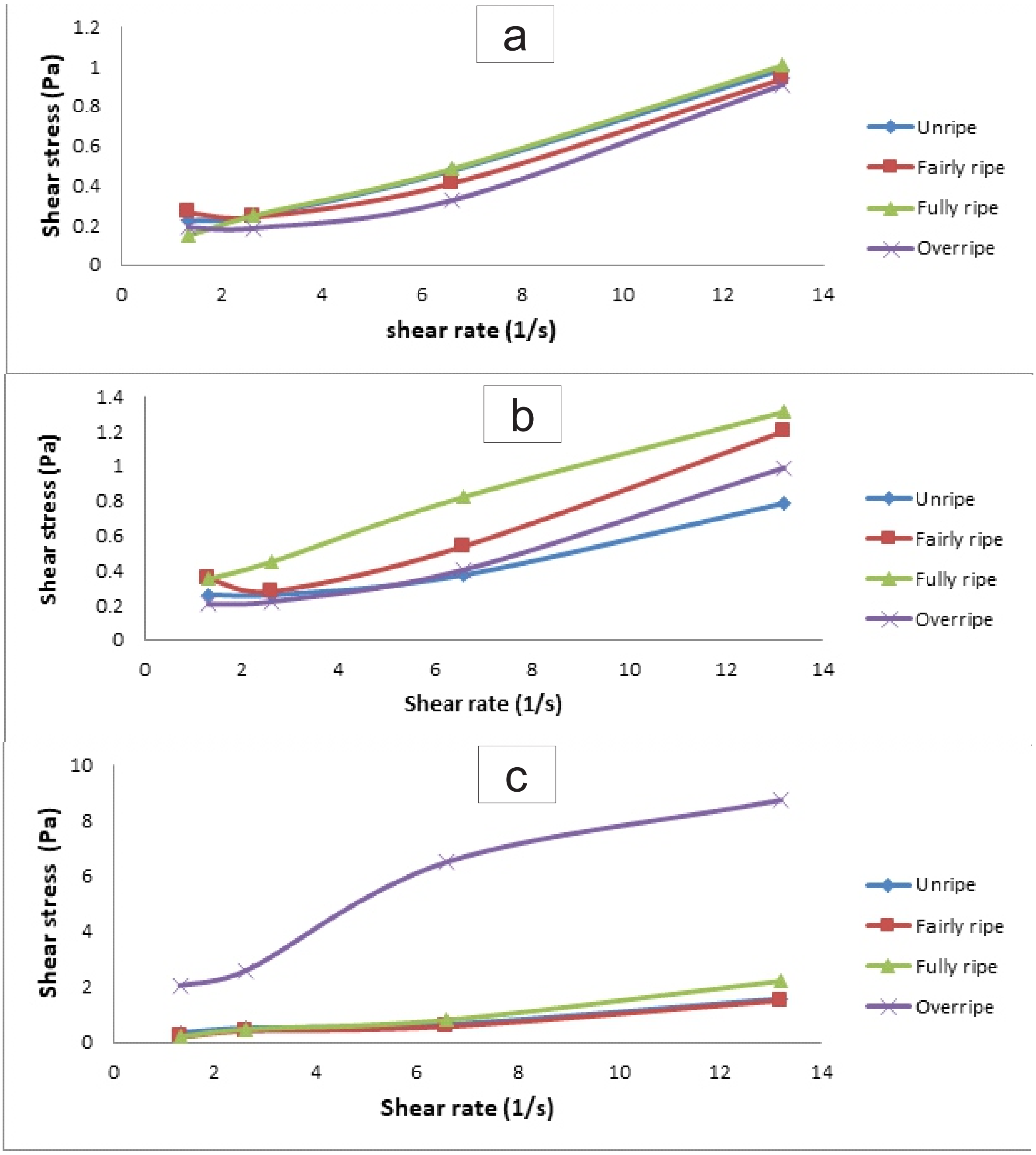

Figure 1: Flow curves showing the relationship between shear stress and shear rate for Orange (a), grape (b) and pineapple (c) Juices at different maturity stages

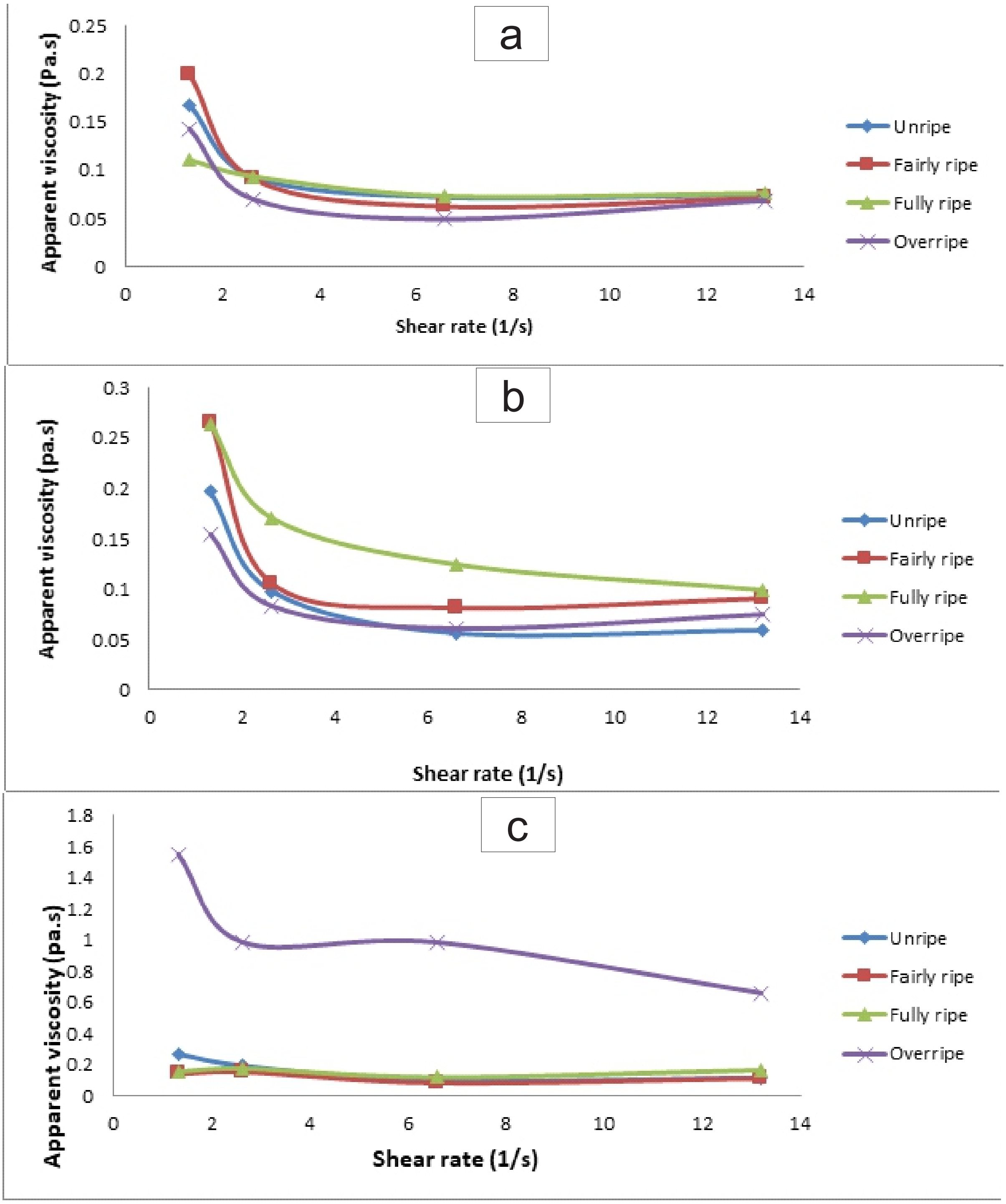

Figure 2: Viscosity curves showing the variation of apparent viscosity with shear rate for Orange (a), grape (b) and pineapple (c) Juices at different maturity stages

In addition, the slopes of the flow curves decreased with an increase in shear rate, as shown in figures 1 and 2. This is an evidence of the decrease in apparent viscosity with increase in shear rate, confirming the pseudoplastic behavior of the juices. All the juice flow curves showed a similar pattern across all the maturity stages except for overipen pineapple which showed a divergent curve from others. Non-Newtonian behavior was observed, as shown by the non-linearity between the shear stress and shear rate applied.

The majority of food fluids present pseudoplastic behavior, the apparent viscosity decreases with an increase in shear rate (Rao and Steffe, 1992; Saravacos and Maroulis, 2001), Rao and Steffe (1992) and Saravacos and Maroulis (2001) reported the pseudoplastic behavior of fruit juices and pulps and verified that this deviation from Newtonian behavior was determined by the pulp content. Rao (1999) and Sato and Cunha (2009) showed that the rheological behavior of fruit juices and pulps was related to the levels of suspended soluble solids as a function of the form, size, and concentration of the suspended particles and the structure of the system. The presence of pectic substances and/or dispersed solid particles is responsible for the non-Newtonian behavior which can be described by the Power Law, Herschel-Bulkley, and Bingham models (Saravacos and Maroulis, 2001; Dak et al; 2007).

Conclusion

The different properties of the selected fruit juices had been studied. It was observed that the juices exhibit a non Newtonian behavior across the different maturity stages and that the apparent viscosity reduces with increase in shear rate. It was also discovered that the shear stress increase with shear rate for the different maturity stages of the fruit juices.

Also, most common fruit juices exhibit complete and variable rheological behavior, that is, shear stress dependence or viscoelasticity. Therefore in the of production, storage and distribution of orange, pineapple and grape juices, there is an inevitable decline in the quality value, if they were not properly handled.

References

Chin, N. L., Gunjal, B. B. and Wachmare, N. J.; (2009) Modelling of rheological behaviour of pummelo juice concentrates using master-curve. Journal of Food Engineering, 93:134-140.

Dak, M.; Verma, R. C.and Jaaffrey, S. N. A. (2007) Effect of temperature and concentration on rheological properties of "Kesar" mango juice. Journal of Food Engineering, 80(4):1011- 1015.

Moreira, P.; (2005). Effect of concentration on the physical properties of cashew juice. Journal of Food Engineering 66 (4):413-417.

Rao, M. A. & Anantheswaran, R. C. (1982). Rheology of fluid in food processing. Food Technology 36(2):116-126.

Rao, M. A. and Steffe, J. F. (1992). Viscoelastic Properties of Foods. London: Elsevier Applied Science.

Reiner, M., (1964). The Deborah Number, Physics Today, p. 62

Sanchez, C., Pelegrine, D. H.; Silva, F. C. and Gasparetto, C. A. (2009). White guava fruit and purees: textural and rheological properties and effect of the temperature. Journal of Texture Studies 40(3):334-345

Saravacos, G. D.; Maroulis, Z. B. (2001). Transport properties of foods. New York: Marcel Dekker.

Sato, A. C. K.and (2009). Cunha, R. L. Effect of particle size on rheological properties of jaboticaba pulp. Journal of Food Engineering 91(4):566-570,

Zuritz, C.A.; Munoz, P.E.; Mathey, H.H.; Perez, E.H.; Gascon, A.; Rubio L.A.; Carullo, C.A.; Chernikoff, R.E. and Cabeza, M.S. (2005). Density, viscosity and coefficient of thermal expansion of clear grape juice at different soluble solid concentrations and temperatures. Journal of Food Engineering 71:143-149.