Physicochemical and Rheological Behavior of African Star Apple (Chrysophyllum Albidium) Juice as Affected by Concentration and Temperature Variation

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Abstract

The viscosity, shear stress and shear rate of African star apple juice (Chrysophyllum albidium) at different concentrations of 8% to 32% total solid concentration and temperature range of 20°C to 70°C were obtained in order to determine the effect of changes in concentration and temperature on the rheological properties of the juice. Also, the physico-chemical analyses of the sample were carried out. Plot of shear stress against shear rate showed that at all concentrations, African star apple juice behaved as a non-Newtonian fluid at temperature below 60°C. At 70°C, however, lower concentration (8% and 12%) behaves non-Newtonian while higher concentrations behave Newtonian. Increase temperature decreases the viscosity of the juice. The knowledge of rheological properties of African star apple juice is essential for the design and optimization of energy process and heat transfer.

Keywords: Viscosity; Chrysophyllum albidium; Newtonian; Juice; Shear stress

Introduction

It has been noted that tropical fruit juices are getting more attention due to the overall increase in ‘natural fruit’ juice consumption as an alternative to the traditional caffeine containing beverages [1]. Chrysophyllum albidium features prominently in the compound agro forestry system for fruits, food, cash income and other auxiliary uses including environmental purposes [2]. It is common throughout the tropical central, East Africa and West African regions for its sweet edible fruits and various ethno-medical uses [3]. Most of the fruits grown in the tropics including African star apple (Chrysophyllum albidium) are under-utilized. Chrysophyllum albidium fruits present a high nutritional value, rich mainly in vitamin C, and this turns it into an excellent nutritional option with an important association between quality attributes and flavor [4].

Fruit juice is a clear or uniformly unfermented liquid, intended for direct consumption, recovered from sound, ripe fruits by pressing and other mechanical means. The juice may be clear or turbid. Fruit juices have become an important part of the modern diet in many communities. They are nutritious beverages and can play a significant part in a healthy diet because they offer good taste and a variety of nutrients found naturally in fruits. They are available in their natural concentration or processed form.

It has been established that knowledge of the rheological properties of food products is important for design and process evaluation, process control and consumer acceptability of the products [5]. Data obtained from rheological data are used for the engineering design of food production [6]. The properties of fruit juices depend on the shear time as well as on the shear rate [7]. It has therefore been established that in industrial operations a product is submitted to a range of shear rate and that the knowledge of the change in rheology with temperature at these shear rate is needed to adequately design the equipment for these operations [8]. Most fluid foods do not have the simple Newtonian rheological model, hence, their viscosities are independent of shear rate or shear stress and not constant with temperature [9]. Therefore complex models are developed to describe their behavior [8].

There are many publications on flow properties of juice concentrates and effects of temperature and concentration which most of them are based on viscometry data [10]. Studies have been carried out on the physicochemical properties of African Star Apple [11,12]. There are insufficient data on the rheological behavior of African Star apple. This work investigates the effects of temperature and concentration changes on the rheological properties of African star apple (Chrysophyllum albidium) by determining the shear stress, shear rate and the viscosity using a Rion-viscometer. The plot of shear stress against the shear rate was made at the different temperature and concentration. In addition, the plot of the viscosity against the shear rate was also made. The two plots were able to show clearly the flow behavior of the African star apple juice.

Materials and Methods

Sample preparation

Fresh fruits of African star apple purchased from a local market in South Western Nigeria were sorted, washed thoroughly with clean water to remove any adhering substances, peeled and its seeds removed. The flesh (3.3 kg) was sliced into small pieces using sharp stainless steel knife and blended until it becomes pure juice. A mesh cloth was used to remove solid materials from the juice. The juice extracted were then filled into sterilized glass bottles and then pasteurized in a water bath at 71.2°C for 30 min for further use.

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Juice concentration

Part of the extracted juice was concentrated under vacuum using rotary evaporator (Rotavapour Brinkmann with Buchi water bath, P-461). After concentrating the juice, the total solids (TS) were determined. The resulting concentrate contained 80 % total solids. Different concentrations of the juice were later prepared by mixing pre-calculated amounts of distilled water to the concentrated (80% total solids) extract. Final juice concentrations (8%, 12%, 16%, and 24%) were obtained for subsequent analysis.

Rheological properties measurement

The shear stress, shear rate and viscosity of the African star apple juice were determined using Rion Visco-meter (VTO4F). Measurement ranges is from 0.3 to 4000 dPa.s. Measurement accuracy is ±10% of indicated value. Rotor speed 62.5 rpm. For each analysis, the filled sample beaker and the spindle were temperature equilibrated. The viscosity, shear stress and shear rate data were obtained. The temperature of the samples in the range of 20°C - 70°C was regulated using a water bath.

Proximate analysis

The proximate analysis was used to determine the mass fraction of protein, fiber, ash, fat, moisture content and carbohydrate in the juice for the various concentrations of the African star apple using AOAC, 2000 methods [13].

Mineral analysis using atomic absorption spectroscopy method

Mineral content is a measure of the amount of specific inorganic components present within a food, such as Ca, Na, K and Cl. Atomic absorption spectroscopy (AAS) is an analytical method that is based on the absorption of UV-visible radiation by free atoms in the gaseous state. The food sample to be analyzed is normally ashed and then dissolved in an aqueous solution. This solution is placed in the instrument where it is heated to vaporize and atomize the minerals. A beam of radiation is passed through the atomized sample, and the absorption of radiation is measured at specific wavelengths corresponding to the mineral of interest. Information about the type and concentration of minerals present is obtained by measuring the location and intensity of the peaks in the absorption spectra. In this work, determination of Calcium, Potassium, Sodium and Magnesium was carried out using AOAC 1990 method [14].

Analyses of other properties

Total solids determination: The total solids were determined as described by Osborne and Vougt, 1979 [15].

Soluble solids (Brix) determination: The brix was determined with the aid of hand-held refractometer, also called Abbe refractometer.

Specific gravity determination: The specific gravity was determined using pycnometer method according to AOAC 2000 methods [13].

Total titrable acidity determination: The total titrable acidity measures the amount of acid, that is, citric acid, malic acid, and acetic acid present in the juice. The total titrable acidity was determined as described by Ishiwu and Oluka, 2004 [16].

Vitamin C determination: The vitamin C content was determined by the spectrophotometric method using ascorbic acid as a reference compound. 10ml of the juice sample was weighed into 10ml of water and mixed together. 200µl i.e. 0.2ml of the extract was pipetted and mixed with 300µl (0.3ml) of 13.3% of trichloro-acetic acid (TCA) and 75µl (0.075ml) of Dinitrophenylhydrazyl (DNPH). The mixture was passed through the atomized sample, and the absorption of radiation is measured at specific wavelengths corresponding to the mineral of interest. Information about the type and concentration of minerals present is obtained by measuring the location and intensity of the peaks in the absorption spectra. In this work, determination of Calcium, Potassium, Sodium and Magnesium was carried out using AOAC 1990 method [14].

| Sample concentration | Moisture Content | Ash | Protein | Fat | Carbohydrate |
|----------------------|-----------------|-----|---------|-----|--------------|
| 8 %                  | 97.73 ± 0.18a   | 0.23 ± 0.18b | 0.26 ± 0.02a | 0.10 ± 0.05a | 1.22 ± 0.04a |
| 12 %                 | 97.53 ± 0.04ab  | 0.24 ± 0.18b | 0.27 ± 0.01a | 0.09 ± 0.01b | 1.24 ± 0.05ab |
| 16 %                 | 97.06 ± 0.04b   | 0.19 ± 0.01b* | 0.30 ± 0.01b | 1.10 ± 0.06b | 1.35 ± 0.07b |
| 24 %                 | 94.71 ± 0.11c   | 0.16 ± 0.00b | 0.39 ± 0.01b* | 1.15 ± 0.01b* | 3.59 ± 0.09b |
| 32 %                 | 92.02 ± 0.13ab  | 0.44 ± 0.02b* | 0.41 ± 0.00b* | 1.20 ± 0.01b* | 0.41 ± 0.04b |

Values with different subscripts on the same column are significant

| Sample concentration | Moisture Content | Ash | Protein | Fat | Carbohydrate |
|----------------------|-----------------|-----|---------|-----|--------------|
| 8 %                  | 149.10 ± 0.32a  | 198.23 ± 0.19a | 213.47 ± 0.29a | 187.23 ± 0.19a | 167.20 ± 0.15a |
| 12 %                 | 170.10 ± 0.06a  | 209.57 ± 0.30a | 235.40 ± 0.21a | 199.50 ± 0.29a | 174.33 ± 0.20a |
| 16 %                 | 205.57 ± 0.30a  | 215.53 ± 0.29a | 246.23 ± 0.23a | 209.50 ± 0.29a | 179.33 ± 0.28a |
| 24 %                 | 241.90 ± 0.59a  | 221.17 ± 0.60a | 255.40 ± 0.26a | 214.50 ± 0.28a | 211.43 ± 0.28a |
| 32 %                 | 255.63 ± 0.32a  | 245.00 ± 0.58a | 277.40 ± 0.31a | 219.57 ± 0.30a | 215.40 ± 0.31a |

Values with different subscripts on the same column are significant

Table 1: Proximate Composition of African Star Apple Juice at Varying Concentration (%).

| Sample concentration | Sodium | Potassium | Calcium | Magnesium | Phosphorus |
|----------------------|--------|-----------|---------|-----------|-----------|
| 8 %                  | 149.10 ± 0.32a | 198.23 ± 0.19a | 213.47 ± 0.29a | 187.23 ± 0.19a | 167.20 ± 0.15a |
| 12 %                 | 170.10 ± 0.06a | 209.57 ± 0.30a | 235.40 ± 0.21a | 199.50 ± 0.29a | 174.33 ± 0.20a |
| 16 %                 | 205.57 ± 0.30a | 215.53 ± 0.29a | 246.23 ± 0.23a | 209.50 ± 0.29a | 179.33 ± 0.28a |
| 24 %                 | 241.90 ± 0.59a | 221.17 ± 0.60a | 255.40 ± 0.26a | 214.50 ± 0.28a | 211.43 ± 0.28a |
| 32 %                 | 255.63 ± 0.32a | 245.00 ± 0.58a | 277.40 ± 0.31a | 219.57 ± 0.30a | 215.40 ± 0.31a |

Values with different subscripts on the same column are significant

Table 2: Mineral Analysis of African Star Apple at Varying Concentration (mg/100g).

| Sample concentration | pH     | Specific gravity | Total Titrable Acidity | Soluble solids | Vitamin C |
|----------------------|--------|-----------------|------------------------|----------------|-----------|
| 8 %                  | 3.66±0.001 | 0.95±0.03      | 0.004±0.01             | 3.20±0.10      | 11.7±0.002 |
| 12 %                 | 3.32±0.02  | 0.99±0.02      | 0.262±0.00             | 3.32±0.08      | 39.4±0.001 |
| 16 %                 | 3.03±0.01  | 0.98±0.01      | 0.325±0.01             | 3.55±0.01      | 39.2±0.002 |
| 24 %                 | 3.15±0.01  | 1.01±0.01      | 0.501±0.02             | 7.02±0.02      | 64.3±0.001 |
| 32 %                 | 3.03±0.02  | 0.98±0.01      | 0.756±0.01             | 8.19±0.01      | 62.0±0.002 |

Values with different subscripts on the same column are significant

Table 3: Other Properties of African Star Apple at Varying Concentration (mg/100g).
was incubated in water bath at 37°C for 3 hours. After 3 hours, 500μl (0.5ml) of 65% sulphuric acid was added and the absorbance was read with the spectrophotometer at 520nm. The concentration of vitamin C was calculated as follows:

\[
\text{Vitamin C (mg/100ml) = } \frac{\text{Absorbance of sample}}{\text{Absorbance of standard}} \times \text{Concentration of standard} \times \frac{20}{5}
\]

**pH determination:** The pH was read directly in 100ml juice samples using the pH meter (Type 3350, Jenway). The instrument was calibrated with standard buffer solutions of pH 7 and pH 4, prior to measuring the pH of samples.

**Statistical analysis**

The data obtained were subjected to statistical analysis. Analysis of variance test was carried out using SPSS.16.0.0 edition. In addition, the significance difference were considered at P<0.05. Flow curves were drawn with the help of MS-Excel 2007.

**Results and Discussion**

The result presented on table 1 showed the proximate composition of African star apple juice concentrations 8%, 12%, 16%, 24% and 32% TS. The result showed that African star apple juice at 8% concentration has the highest moisture content followed by 12% concentration. This, however, is not far-fetched, it is based on the fact that the 8% concentration has the higher percentage of reconstitution i.e. dilution with water, followed by 12% concentration. The moisture ranged from 92.02%-97.73%, but these two values were not significantly different (P<0.05) from each other. Moreover, the 32 % concentration of African star apple juice has the highest protein content followed by 24 % concentration. The protein content ranged from 0.27% to 0.41%. However, these two values are in conformity with the values reported by Nwadingwue [17] for protein content of African star apple juice.

Table 2 showed the mineral analysis of African star apple juice at different concentrations ranging from 8%-32%. The result showed that 32% juice had the highest mineral contents i.e. Sodium, Potassium, Calcium, Magnesium and Phosphorus followed by 24% concentration, while 8% had the lowest mineral content. This followed the same pattern when each mineral constituent are compared with one another. Furthermore, both 32% and 24% concentration are significantly different at P<0.05 from other concentrations.

The results presented on table 3 showed the physico-chemical analysis of African star apple juice at 8%, 12%, 16%, 24% and 32% concentration levels. The result showed that the pH values of 8% and 12% were higher. The pH content ranged from 3.03-3.66. This pH range showed that African star apple juice at various concentrations has a low pH and this makes it a highly acidic juice. Its acidic nature is responsible for the tartness of the juice. Furthermore, since the 16% and 32% concentration level have a low pH, then, they are the most acidic. The pH values are not significantly different (P<0.05) from one another. Also, in terms of vitamin C, 32% concentration level had the highest vitamin C content followed by 24% concentration. However, the two concentrations are significantly different from each other.

The flow curves obtained at different concentrations (8%, 12%, 16%, 24% and 32%) in the temperature range (20°C-70°C) are shown in figures 1 to 7. Figures 1 to 6 showed that at the indicated temperature and temperature changes, African star apple behaved generally as a non-Newtonian fluid and precisely, as a shear thickening (dilatants) fluid. Though at higher concentrations, the behaviour is less pronounced but as the concentration decreases the behavior becomes more pronounced. This is in accordance to the work of Keshani et al. [9] on the effect of temperature and concentration on rheological properties of pomelo juice concentration. It was established that as concentration increases, the flow behavior was Non - Newtonian while at lower concentration pomelo juice tends to Newtonian behavior.
where the shear thickening behavior of the juice is still retained (Figure 6).

Conclusion

In conclusion, the African star apple juices at different concentrations and temperature range exhibits non-newtonian behavior at all concentrations and temperature up to 60°C. Varying the concentration and the temperature affected the degree of the behavior of juice. The behavior of the juice at around 500 S⁻¹ could be attributed to the presence of soluble solids/concentrations mostly pectins and

Figure 5: Plot of Shear Stress vs Shear rate at 60°C.

Figure 6: Flow curves at 70°C of African star apple juice at different concentrations.

There are few exceptions at 30°C where the behavior at concentrations 12% and 24% overlapped. Also, at 70°C concentrations 12% and 32% overlapped. These are clear indications of the effect of temperature on the behavior of the juice. In fact at 70°C, the behavior at 16 % and 24% were not conspicuously absent. This is an indication that increasing temperature had adverse effects on a shear thickening fluid.

Figure 7 gave a clearer picture of the effects of temperature changes and concentration changes on African star apple juice. V1 to V6 stand for temperature ranges 20°C to 70°C respectively. They all behaved as shear thickening fluid though the degrees of their behavior also varied with juice concentration and temperature in accordance with the established principle that temperature and concentration variations affected flow behavior of juices [18,19]. In fact, it was at 40°C that it juice behaved most as a shear thickening fluid (as observed from the perfect shear thickening curve). Others (V1, V2, V4 and V5) which stand for temperature 20°C, 30°C, 50°C and 60°C respectively all had lowest viscosity when the shear rate is 500 S⁻¹. The only exception is the behavior of V7 where the juice behaves shear thickening up till 100 S⁻¹ after which it takes the shape of a Newtonian fluid. This could mean that higher temperature would affect drastically the behavior of fluid, hence, storage and transport of fluid at higher temperature could affect the behavior of the fluid. The only exception is at lower concentration

Figure 8: Rheogram for Power law model at 8% juice concentration and 20°C.

Figure 9: Rheogram for Power law model at 12% juice concentration and 20°C.

Figure 10: Rheogram for Power law model at 32% juice concentration and 20°C.

Figure 11: Rheogram for Power law model at 8% juice concentration and 40°C.
also discontinuous phase substances, such as fibrous materials when water acts as a continuous phase. This is in agreement with Ibarz et al. [20], when he found a small pseudo-plasticity in juice flow curves.

$y = x - 1.301$

$R^2 = 1$

![Figure 12: Rheogram for Power law model at 12% juice concentration and 40°C.](image)

![Figure 13: Rheogram for Power law model at 24% juice concentration and 40°C.](image)

![Figure 14: Rheogram for Power law model at 16%, 32% juice concentration and 40°C.](image)

![Figure 15: Rheogram for Power law model at 8%, 16% juice concentration and 60°C.](image)

Also it has been observed that viscosity increases with increasing fluid concentration except at higher temperature where the viscosity remains the same even though the concentration increases. The Power Law model plots of rheological behavior at varying concentrations and temperature were shown in figure 7 to 18. The plots were all linear ans the $R^2$ values ranges from 0.954 to 1. African Star Apple therefore conform to the Power law model and also to the non-Newtonian model, also, as shown in figures 1 to 4.

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