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Physicochemical and Rheological Characterization of Melon Pulp (*Cucumis melo*) Cultivated in the North of Bolívar Department, Colombia

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***Abstract*— Melon (Cucumis melo) is a fruit of great national importance. However, it is not exploited in our region due to producers' insufficient negotiating capacity and the lack of infrastructure and technical training, which causes losses of these products, especially at harvest time. Therefore, it is necessary to study its physicochemical and rheological properties to optimize the different processing methods. The main objective of this research is the study of the physicochemical and rheological properties of fresh melon pulp (Cucumis melo) from the northern area of the Bolívar department, Colombia, as a contribution to science and agro-industry, for which the physicochemical characterization was performed following AOAC methods, and the rheological characterization was performed by flow tests at steady state in a temperature range of 10-60°C. The pulp rheological properties evaluation were analyzed according to the temperature variation. The tests were conducted using a Modular System Rheometer Haake Mars Advanced 60. The pulp yield was 83.74% of the whole fruit; physicochemical parameters were similar to those studied previously by other authors. The melon pulp had a non-Newtonian pseudoplastic behavior (shear thinning) in all cases with reduction of temperature, the relation between the viscosity and the deformation rate adjusted the Carreau-Yasuda model (R2> 0, 97264). These results provide information on the melon pulp rheological behavior and may have potential application in the agro-industrial sector for the design of processes to manufacture products from this raw material.**

***Keywords*—Melon (C.melo); physiochemistry; rheology; pulp; pseudoplastic; apparent viscosity; food industry.**

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I. INTRODUCTION

In recent years have been found an increase in the demand for healthier foods and commercial interest for fruits with high nutritional power and nutraceutical properties, usually in countries such as Colombia, since it is characterized by having a privileged geographic position that makes it potentially rich in fauna and flora [1]. In this regard, tropical fruits have gained tremendous interest in the market of fresh and processed products, among them, the melon (Cucumis melo). However, in the scientific-technical aspect of tropical fruit varieties, in the northern area of Bolívar, there is a lack of exploitation of their potential as a source of food, raw materials, and even medicines [2].

According to data from the agricultural production and livestock of the Ministry of agriculture and rural development in Colombia, in 2016, the Department of Bolivar was the region with the largest area planted with melon (Cucumis melo), a total of 1266 ha [3]. Most of this cultivated area is located in the north of Bolivar in municipalities such as Mahates, San Estanislao, and Santa Catalina. It is necessary to take advantage of this type of crops in order to avoid more than 1 billion post-harvest losses that are presented in crops and carried out transformations through the knowledge of their properties, allowing to have healthier products to consumers who are increasingly interested in this aspect [4]

The melon (Cucumis melo) is a plant with creeping stems, with attractive cultivation of the Cucurbitaceae family due to the high appreciation of its fruit, which is a pepónide berry with a large number of species [5]. This fruit is attributed to different origins, such as Pakistan or Iran, as Gómez-García et al.,[6] mentioned. Melon (Cucumis melo) is currently valued for its characteristic sweet taste and its high wáter content, but in the middle age it was harvested when the fruit was still young to give it a similar use to cucumber, and at the end of this period in the XV century begins to recognize the value of the fruit by the properties we know in contemporary time [7]. The melon fruit (Cucumis melo) is mostly water, and it usually contains 92% of this component. It also has beta carotene, which gives it the orange color, a precursor of vitamin A. It is also an excellent source of vitamins B, C, and minerals, especially K, Fe, Ca, Na, and Mn [8], [9]. This fruit is also rich in anti-inflammatory cucurbitacin B and cucurbitacin. The primary fatty acid is linoleic (64.7%), followed by oleic (16.4%), palmitic (9.1%), stearic (5.2%), and peanut Acid (1.5%). Cantaloupe can prevent oxidative stress and excessive inflammation [10]. Naturally, in pulps obtained from fruits, we find a composition of solids in dispersion in an aqueous phase like most pulp. These particles directly infer the stability and rheology of food, either by size, shape, disposition, chemical composition, and concentration in these dispersed particles' pulp. It depends on the nature of the fruit and the treatments applied in obtaining the pulp [11].

Pulps are generally transported through pipes, stirred and mixed in tanks with other raw materials, pasteurized, and evaporated in heat exchangers and continuous evaporators. For these unit operations to be technically and economically viable, it is essential to know the pulp properties. [12], [13]. Among these properties, rheological behavior is one of the most important, rheology is a fundamental part of the characterization of food, and it is defined as the science in charge of studying the deformation parameters of matter, which vary depending on the transformation from food processing to finished product production [14]. Through rheological studies, it is possible to find the link or relationship between the stress applied to the food matrix and its ability to flow when a stress variation is applied [15]. It should be clear that the concept of fluid corresponds to bodies that can move or flow under the application of an effort and a transformation without return [16].

Nowadays, it is essential to study food rheology to know the consistency and flow of foods under the influence of specific applied forces to understand the fundamental physicochemical principles of "structuring" food materials and their interactions with other compound additives [17]. We work with fluids (mainly liquids) in most processes or operations in the food industry. The operations, such as concentration, pasteurization, and pumping, predict specific alterations in the formulation, processing, transportation, and storage. The operations determine the viscosity and how temperature affects the behavior of food. Also, it determines the properties, such as product quality, calculation, equipment design, and flow operations in food processing. The properties are subject to achieve high yields in the operations. In the food field, there is a high number of rheological models, which try to describe the rheological behavior and the type of fluid present in the matrix [16], [18], [19]. Most of these do not comply with Newton's viscosity law; they present a behavior like non-Newtonian fluids. The latter's behavior can be described by the law of power or by the Herschel-Bulkley model, in the case that they present non-zero yield stress [20].

This research aims to study the physicochemical and rheological properties of fresh melon pulp (Cucumis melo) to contribute to science and agro-industry to simulate the different processes and applications to which they are submitted for the development of products. This research is of great importance for the equipment design that allows the transform of fruit pulps and calculates the power required for transport by feeding pipes in the particular case of melon (Cucumis melo) or any vegetable resembles its rheological behavior.

II. Material and Method

The methodology for this work can be detailed, taking into account: (A) the materials used with their descriptions; (B) physicochemical characterization; (C) description of the rheological tests, these being steady-state flow tests and (D) statistical analyses.

A. Materials

Fruits from the northern area of Bolívar were harvested, grown on farms, commercialized in market places that include Mahates, San Estanislao, and Santa Catalina's municipalities characteristics of full commercial maturity and with no evidence of any mechanical damage. The period of exploration was made according to the harvest seasons given during two months that elapsed between June-September of 2018. In the IFCRA laboratory of the University of Cartagena, the fruits were weighed, washed, cut in longitudinal halves, and pulped manually, eliminating the epidermis and seeds. The size was then reduced and finally was prepared with a blanching at 65 ° C for 10 minutes, stored in closed containers, and placed in refrigeration at 4°C, based on the conditioning carried out by Andrade [21].

B. Physicochemical characterization.

Physicochemical analyses were performed by triplicate, using standard methods AOAC.

Determination of the pulp yield. It was established by the pulp weight's relation concerning the total weight of the fruit (Equation 1). The result was expressed as a percentage (%).

$$\%Pulp\ yield = \left(\frac{Pfinal}{Pinitial}\right) * 100 \qquad (1)$$

Soluble solids content. The soluble solids content was determined by a refractometer BRIXCO at 20C, according to method 932.12. Titratable acidity. It was determined as citric acid, according to the method 942.15. pH. The pH was determined by direct reading in the HANNA HI 9124 pH meter, at 25ºC, according to the method 981.12. Maturity index: was obtained from the relation between the total soluble solids and titratable acidity [22], using equation 2.

$$M.I. = \frac{T.S.S.}{Acidity} \qquad (2)$$

- M.I. = maturity index and T.S.S. = total soluble solids.

C. Rheological evaluation.

Static flow tests were carried out obtaining viscosity curves at temperatures of 10, 20, 25, 40, and 60 ° C of the samples without previous history of shear, in a Haake Mars 60 Modular Advanced Rheometer System using a plate-plate geometry of the rough surface of 35 mm and separation between plates of 1.0 mm gap. In a range of shear rates between 0.001 and 1000 s-1. In this study, before measurement, all samples were allowed to stand for 600 s to allow relaxation of the same, the temperature of the samples was held constant at 20 ± 0.1 ° C, using a Peltier system to control the temperature, based on the methodology used by Quintana [11].

D. Statistical analysis

The data were analyzed by ANOVA (unidirectional) using the SPSS software (version 17.0 for Windows) in order to determine statistically significant differences ($p < 0.05$) between the samples. All tests were performed in triplicate.

III. Results and Discussion

After performing the mass balance, an average yield of 83.74% was obtained, the remainder being a non-edible portion of the fruit (peel and seeds).

A. Physicochemical Composition.

The values of pH, soluble solids (° Brix), titratable acidity, and maturity index obtained from the pulp of melons harvested in the north of the department of Bolívar, Colombia, are in Table 1. The pH value obtained is above the one reported by the FDA [23], which establishes a range of 6.13 to 6.53. However, there are studies where the pH value was below this, it was 5.96 ± 0.21 [24], on the other hand, in a study carried out by García and collaborators [25], they found pH values ranging from 6.18 to 7.47 for different varieties of melon, similar to those found in this study. It concludes that the variation in the fruit's pH depends on multiple factors such as the type of soil where it was grown, the season, the crop area, among others.

The values of *C. Melo* pulp's titratable acidity was 0.0938% citric acid, which is similar to the results found in studies of [26] where they obtained a titratable acidity of 0.09% citric acid. It is important to note that sensory acidity is not directly related to a finished product's pH. It can happen in the case of fruits with acid flavor, which may not have a low pH and the opposite way. This can vary due to the pulp's buffer capacity when it is at low pH and the combination of acids present in the pulp [27].

TABLE I
PHYSICOCHEMICAL COMPONENTS OF FRESH MELON PULP (*CUCUMIS MELO*).

Parameters / Units.	Results
Ph	6.72±0,03
Soluble solids (°Brix at 20 °C)	9±0,0
Titratable acidity (% citric acid)	0.0938±0.0007
Maturity Index (TSS/ Acidity)	95.91±0.65

The pH is a handy parameter in the food industry since it is fundamental to control microorganisms' development, the systems enzymatic activity, the clarification process, and stability of juices and beverages. It is also essential in other products made from fruit pulp, such as jellies and jams. Firmness, color, and taste are determined by the concentration of hydrogen ions [28]. Organic acids, responsible for the acidity of fruits, are the by-products of fruit metabolism and play a fundamental role in flavor and aroma development. However, titratable acidity and pH measurements can also provide an estimate of the spoilage degree of certain types of food, which can be confirmed by the development of unusual acidity or alkalinity. Very high acidity values are related to low-quality raw materials or the excessive addition of acidulants, while low acidity values are probably due to the fruit pulp's dilution to reduce soluble solids (°Brix). [29]

The soluble solids percentage obtained was 9°Brix, similar to the results found by [30] and [31]. The results are closely related or influenced by the number of sugars in the fruit [32]. The soluble solids in fruit pulp contain essential compounds responsible for consumers' taste and acceptance, the most critical being sugars, organic acids, soluble pectins, anthocyanins, and other phenolic compounds ascorbic acid [33]. It is important to emphasize that the total soluble solids used in the refractometry measurement are used to indicate total sugars in the fruits and indicate the maturity degree [34].

The average maturity index of the melons studied was 95.91. This result is slightly lower than 96.24 [35]. This is due to the reliable content ratio with acidity, which was very close in both studies. This index is closely related to harvest time and environmental changes; However, this variable is susceptible to changes in the industry when acidity and ° Brix corrections are made, through any process that increases or decreases the concentration of the acids or the total solids of the product [26].

B. Rheological characterization.

After performing static flow tests having temperature variations, the change in viscosity concerning the deformation speed was observed. Figure 1 shows the melon pulp's viscous flow curves (Cucumis melo) is a function of the shear rate. The curves are in a temperature range of 10-60 ° C.

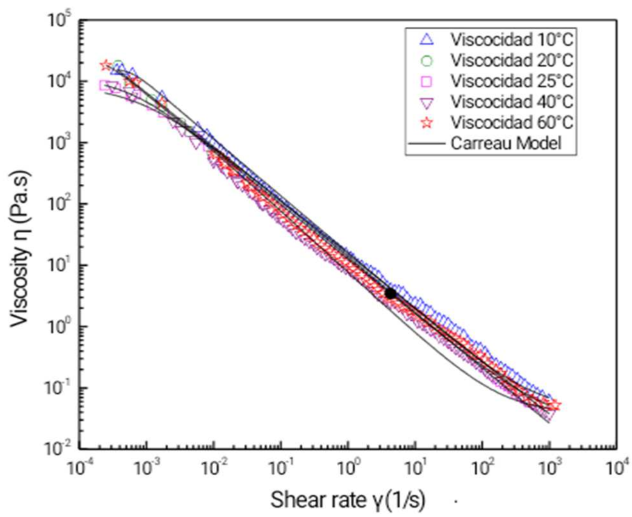

Fig. 1 Viscous flow curves of C. Melo pulp at different temperatures (10, 20, 25, 40, 60 ºC) adjusted to the Carreau-Yasuda model.

The results obtained at different temperatures of 10, 20, 25, 40, and 60°C. It has indicated the behavior of a non-Newtonian fluid of the pseudoplastic or fluidizing type (Shear-tinning). It was characterized by a possible decrease in viscosity, which is caused by increased shear rate [36] following a tendency to establish a constant value of viscosity at low shear rates η_0 and at high shear rates η_∞ [11]. This phenomenon is possibly due to the amount and distribution of particles mentioned by Bhandari [37] since the pectin's nature, and the number of dispersed particles are determinants in the flow pulps properties. This pseudoplastic behavior can be explained by breaking a reticular structure of polysaccharide molecules during shearing; consequently, a lower viscosity results from the increase in the deformation rate [28]. In the developed mechanical spectrum, the variation of the melon pulp viscosity to temperature does not significantly differ, allowing it to be used in different industrial processes that include temperature variations for the development of new products from this raw material.

Results with similar behavior have been previously found in studies of the squash pulp (Cucurbita moschata) [38], papaya pulp (Carica papaya) [11], the jew's ear *(Auricularia auricula-judae*) [39], and in mango, papaya and peach purees [40]. Due to the rheological behavior presented by the melon pulp (Cucumis melo), the given values of viscosity vs. shear rate were adjusted to the Carreau-Yasuda model (equation 2) [41], which presented a minimum correlation coefficient R^2 of 0.97264.

$$\eta = \eta_\infty + (\eta_0 + \eta_\infty)[1 + (\lambda_c\, \gamma)^a]^{\frac{n-1}{a}} \quad (3)$$

When subjected to low deformation velocities, this model describes fluids that behave like Newtonian fluids, being treated as constants. When they undergo a considerable increase in deformation speeds, they begin to behave like a non-Newtonian fluid, in such a way that their viscosity decreases, which is described by the law of power. On the other hand, when they begin to reach very high deformation speeds, it tends to be constant to behave like a Newtonian fluid [42]. This model consists of five parameters, where η_0 corresponds to the Newtonian viscosity at low deformation speed values, η_∞ is the Newtonian viscosity for values of deformation speed when it tends to infinity, λc is a Carreau time constant, a is the Transition control factor that is a dimensionless constant, n corresponds to the parameter of the power-law model. In the case that n = 1, the model is reduced to the linear Newtonian model, for example, the Navier-Stoke equation. For fluidifying liquids, n <1, the viscosity decreases with the increase in deformation speed, indicating viscosity dependence on shear rate [43].

The parameters used to adjust the Carreau-Yasuda model are shown in Table 1. The results proved that the "shear-thinning" re-fluidizing behavior, since the flow behavior index values were lower to unit n <1, for different temperature conditions. The viscosity decreases with the speed of deformation. Therefore, it is not considered an increase or decrease in the fluidifying character of the pulps. However, temperature changes affect viscosity values. The model adequately adjusts the steady flow behavior of melon pulp (Cucumis melo), with an average of correlation coefficients (R^2 = 0.9866).

As the melon pulp (*Cucumis melo*) presents similar rheological behavior to other food materials, it can also be adjusted to other rheological models that allow the flow description, mainly fruit pulps. Among the models used for this characterization, we find the mathematical model of the power law of Ostwald de Waele, which is the case of a squash (Cucurbita moschata) and sesame (Sesamum indicum) cream [44], some beet pulp homogenized under pressure [45], the *nispero* pulp (*Achras sapota*) [21], varieties of guava pulp (Psidium Guajaba L.) [46], among other things. Among the models, the one that best adapts to describe inelastic fluids independent of time is the model of Herschel and Bulkley as in the case of taro homogenized pulps (Colocasia esculenta (L). Schott) [47]. The temperature effect on the apparent viscosity of fluids in food (at constant cutting speeds) could be explained by the Arrhenius equation [48], which is expressed:

$$\eta = Aexp\left(\frac{E_a}{RT}\right) \quad (4)$$

TABLE II
RHEOLOGICAL PARAMETERS OF THE CARREAU-YASUDA MODEL FOR THE MELON PULP VISCOSITY AT DIFFERENT SHEAR RATES, AT TEMPERATURES OF 10-60°C.

Temp.	η_0	η_∞	λ_c	a	n	R^2
10°C	13745.73	4.30 x 10^{-4}	2164.56	0.90	0.08	0.997
20 °C	27147.06	2.0 x 10^{-3}	5111.16	6.96	0.12	0.972
25°C	14898.33	4.21 x 10^{-3}	1000.19	2.12	0.02	0.981
40°C	21211.88	1.79 x 10^{-4}	4096.10	0.80	0.09	0.993
60°C	24492.24	2.5 x 10^{-2}	4721.49	3.01	0.10	0.987

Where A is the pre-exponential factor and Ea the activation energy, which is a parameter that evaluates the thermal dependence, for the same temperature increase, when the value of activation energy is higher, then the effect it produces is more significant (J / mol), R is the gas constant (8.314 J / mol K), and T is the temperature (K). In which the apparent viscosity decreases in an exponential function with temperature [49]. The deformation velocity of 17 s^{-1} was selected for this case, considering that the flow operations (mixing and agitation) in pipes oscillate in speeds ranges of shear of 10-1000 s-1 [50]. Likewise, it observed that the melon pulp is appropriately adjusted by the Arrhenius equation (4) because the values of correlation coefficients (R^2) were higher than 0.92.

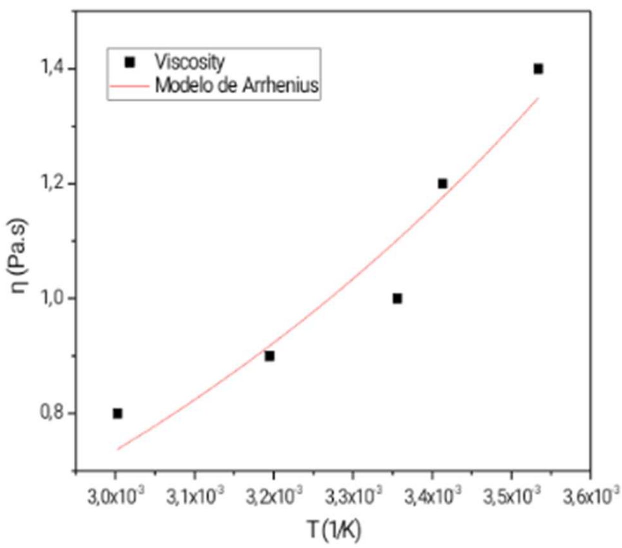

Fig. 2 Variation of the values of η obtained at 17 s-1 as a function of temperature and adjustment to the Arrhenius equation.

Activation energy values for melon pulp (*Cucumis melo*) in this case (Ea = 20601 J / mol) was higher than those reported in plum pulp (Ea = 15080 J / mol) [51].; papaya pulp (Ea = 10500 J / mol) [11] and tomato paste (Ea = 8600-13000 J / mol) [52]. The value of activation energy indicates how strong is the interaction between polysaccharide chains and internal molecular interactions. The higher the activation energy, the better the temperature sensitivity [53]. Therefore, the melon pulp's internal structure is more sensitive to temperature than those pulps fruit cited. The activation energy is necessary for the molecules' movement when the liquid's temperature increases; they decrease more easily due to the higher activation energy at high temperatures. In this case, an increase in temperature causes a decrease in the liquid phase's viscosity, increasing the suspended particles' movement and causing a decrease in the pulp viscosity [54].

IV. Conclusion

The temperature changes did not significantly affect the melon pulp's viscosity in the range of strain rate studied, facilitating the use of this raw material in different pulp transformation processes. It was found that the activation energy is high compared to different fruit pulps studied, which means that its high content of water and fiber. Therefore, care must be taken when reaching high temperatures close to 100 °C, which can cause unfavorable changes that significantly affect the rheological and nutritional properties.

The results provide relevant information on the rheological behavior of melon pulp that could have a potential application in the agro-industrial sector for the design of processes that include the elaboration of products with added value and specialized equipment design to process melon pulp, controlling variables such as pH, temperature, humidity, among others.

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