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Rheological Characteristics of Fresh and Freeze-Dried Reconstituted Juices Obtained from Some Non-Traditional Fruits.

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ABSTRACT

This study aimed to evaluate the rheological characteristics of fresh and reconstituted juices obtained from acerola, annona and cactus fruits at 25°C. The relationship between the applied shear rates and the corresponding shear stress response was not linear indicating the non-Newtonian behavior of the juices obtained from acerola, annona, and cactus fruits. The magnitude of the obtained shear stress values varied according to the type of fruit and its composition. Maximum shear stress responses at shear rate of 145.8s^{-1}were122.97 and 59.87 Dynes/$cm^2$for juices obtained from acerola and annona, respectively. On other side, the juices of yellow and red cactus fruit recorded lower shear stress values at the same shear rate (145. 8s^{-1}), being 27.68 and 30.75 Dynes/cm^2, respectively. According to power law equation, the n-value (behavior index) of tested juices was in the range of 0.222 to 0.5203 indicating the pseudoplastic behavior of the tested fruit juices. The highest values of consistency coefficient (K-value) was recorded for acerola juice (14.70 Dynes.s^n /cm^2), while the lowest values was recorded for the enzyme treatment of red cactus juice (4.766 Dynes.s^n /cm^2). The highest values of R^2 were recorded for enzyme treated yellow cactus juice (0.998), while the lowest values were recorded for annona juice (0.868).The rheological parameters of the reconstituted freeze dried juices showed that the n-values were in the range of 0.562 to 0.695, being higher than their corresponding n-values of the fresh juices. The lowest values were recorded for red cactus reconstituted juice. The highest values of R^2 were recorded for yellow cactus juice (0.991), while the lowest values were recorded for reconstituted freeze-dried red cactus juice (0.974). The highest values of consistency coefficient (K-value) of the reconstituted juices were recorded for yellow cactus (2.733 Dynes.s^n /cm^2), while the lowest values were recorded for Annona (1.030 Dynes.s^n /cm^2).

Keywords: Acerola, cactus pear, Annona, Freeze drying, Rheology, Apparent viscosity.

INTRODUCTION

Food drying processes involve many critical variables determining the final product quality and shelf-life. Drying temperature and drying time are of importance to determine a good process. Drying processes being done at lower temperatures are of indication of a proper of food drying. The most critical physical properties are color and structure. In a way to obtain dry food materials with high quality, freeze-drying is considered the best method of water removal. Comparing the other methods of food drying, it yields final products of highest quality (Maria, 2014). The rheological property of the food should also be considered so as to provide a better understanding of the structural organization of the food. It is also important for process engineering calculations, equipment such as agitators, pumps, heat exchangers, piping and homogenizers (Conceicao *et al.*, 2012). Taking into consideration the consumer demand for processed foods with high quality, there is a need to identify the changes in rheological properties of foods in processing operations that may affect their overall acceptability. So, it is important to detect the rheological behavior of fruit pulps, and to develop the models that describe the rheological behavior in terms of product concentration and processing temperature (Nindo *et al.*, 2007). Acerola fruit (*Malpighia emarginata* D.C.) is a of short shelf life, although it is of a high nutritional value, mainly vitamin C, carotenoids and anthocyanins, antioxidant pigments whose combination is responsible for the fruit red color (Lima *et al.*, 2005). Several quality parameters, such as water activity (a_w), glass transition temperature (T_g), vitamin C content, shrinkage and rehydration capacity of the freeze-dried of acerola fruits*(Malpighia glabra L.)* were studied by Marques *et al.*, (2007), who observed that freeze-dried acerola fruits can be easily reconstituted. The rheological behavior of acerola pulp at concentration of 5.5, 7.5, 9.5, 11.5, and 13.5 Brix and temperatures of 20, 30, 40, 50, and 60˚ C.were examined by Pereira *et al.*, (2014) The rheological behavior, specifically apparent viscosity versus shear rate, was influenced by both the soluble solids content and temperature. The Herschel-Bulkley model provided the best statistical adjustments, and was then used to determine the rheological parameters. Apparent viscosity was correlated to the temperature by the Arrhenius equation. Acerola pulps were shear thinning. The rheological parameters of mango juice by using rotational viscometer at temperatures 20, 30, 40, 50, 60 and 70 °C; and at concentrations of 5.17%, 8.51%, 12.38%, and 17% total solids were investigated by Manish *et al* .,(2006). The power law model was fitted to the experimental results. The value of flow behaviour index (n) was less than unity (0.24–0.41) at all temperature and concentrations indicating the shear thinning (pseudoplasticity) nature of the juice. Arrhenius model was able to relate the consistency index, in the range of 2.22–385.24 Pa. s^n with absolute temperature. Consistency index was related to solid concentration by a power equation. The activation energies were found to be in the range of 1.66–11.35 kJ/mol K.

The rheological parameters of pasteurized and frozen acerola cashew apple and mango pulps were in accordance with the Ostwald-de-waelle, Herschel-Bulkley and Casson's models under different temperatures (Da-Silva *et al.*, *(*2012). The rheological measurements were made by means of a concentric cylinder rheometer adjusted to 8,15,25,35 and 45˚C. With increasing strain rate and decreasing temperature, the pulps decreased in their apparent viscosities. The acerola, cashew apple and the mongo pulps exhibited non-Newtonian behavior and pesudoplastic characteristics.

Annona fruits was introduced to Egypt in 1806 .*Annona Squamosa* (Known as Balady Cv.) and some other cultivars which are thought to be clones of *A.Squamosa* (such as *Abd El-Razik* Cv.) (A*bd EL-Monem et al.,* 2003). Annona fruits contain a considerable amount of polyphenolic compounds. These compounds are antioxidants and may help to prevent diseases associated with oxidative diseases (Roesler *et al.,* 2006). Antioxidant activity could be related to the presence of bioactive constituents (Barreira *et al.,* 2008).

The effect of freezing rate on quality parameters of freeze dried soursop fruit pulp was studied by Ceballos *et al.,* (2012). The final moisture and ascorbic acid content,water solubility, wetability and color of freeze dried soursop fruit pulp treated with maltodextrin were detrmined. After a constant drying time of 6hr, the moisture content of the dried samples was in the range of 8.68-13.09%, being higher for higher values of freezing rate. Freeze –dried powders were much brighter in color compared with maltodextrin treated pulp among the freeze dried samples. Those samples prepared with higher freezing rates were lighter in color.

Telis-Romero *et al.,* (2007)found that maltodextrin was added to the pulp in order to prevent stickiness between particles and the consequent bed collapse. Pulps were initially concentrated, resulting in pastes with different soluble solids content, and a constant fraction of maltodextrin was guaranteed in the final pulp samples. Including maltodextrin was evaluated and the effect of pulp apparent viscosity on pressure drop and minimum vibro-fluidization velocity were investigated..The negative effect of increasing apparent viscosity could be attenuated by increasing the fluidized bed vibration intensity, which could prevent stickiness between particles.

Manjunatha and Raju(2015) examined the effect of maltodextrin (MD) and gum Arabic (GA) with original juice (OJ) on viscosity of reconstituted beetroot (*Beta vulgaris* L.) juice powder at different solid contents (Xs) 10 to 50% and wide range of temperatures 10 to 85°C. They observed tha all of the reconstituted beetroot juice behaved like a Newtonian fluid. The Newtonian viscosity (η) ranged from 4.47 to 86.99, 4.76 to 176.15 and 5.60 to 1561.77 mPa s for original, maltodextrin (MD) and gum Arabic (GA) based juices, respectively, depending on the solid content and temperature applied. The Newtonian viscosity increased significantly ($p<0.05$) with increase in solid content, whereas it decreased significantly ($p<0.05$) with increase in temperature.The temperature dependency of Newtonian viscosity of beetroot juice was described by Arrhenius equation. The flow activation energy (Ea) was markedly affected by type of carrier materials, and is increased significantly ($p<0.05$) with increase in solid content.. A combined single equation relating Newtonian viscosity (η) to solid content and temperature was established.

The aim of this work was to process some non-traditional fruits (Acerola,Annona and cactus) grown in Egypt to juices and to evaluate their rheological parameters, which are very important for possible industrial use of these fruits.

MATERIALS AND METHODS

Fully mature acerola (*Malpighiaglabra L.)*,was obtained from farm of Agriculture Research Center Institute, while annona *(Annona Squamosa* L.) and cactus pear (*O. ficus-indica*) fruits were obtained from EL-Oboor market during the summer and winter season of 2012.

All chemicals, used in this work were of analytical grade and bought from El- Gomhoria Co., Egypt.

About twenty kg of cactus pear fruits, (*O. ficus-indica*) were washed in water and then peeled by hand and a knife for obtaining peeled fruit (yield 59%). Seeds and mesocarp fibers were removed. The ratio of pulp was 59%, while the ratio of peels was 41% and seeds ratio was 0.5%. Pectinase was added in quantity of 1.8g/L puree and the puree was kept for 4hr at room temperature without modification of the pH. The puree was finally strained by using chesse sheets with pore size of about 200µm after the enzymatic treatment step has been completed as seen in Fig. (1).

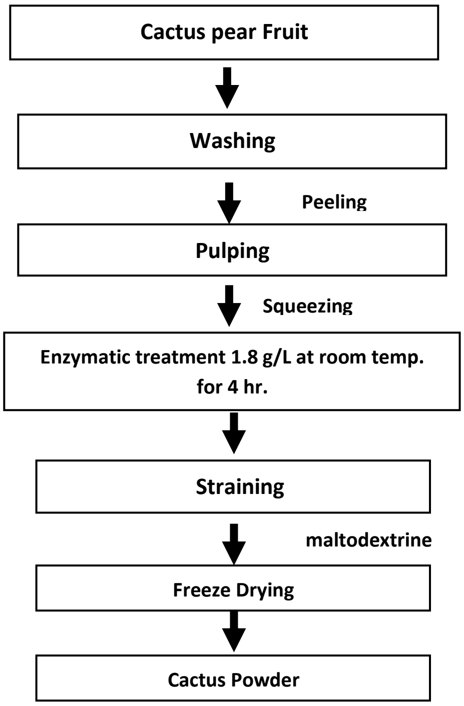

Fig. (1): Processing steps of freeze dried Cactus juice

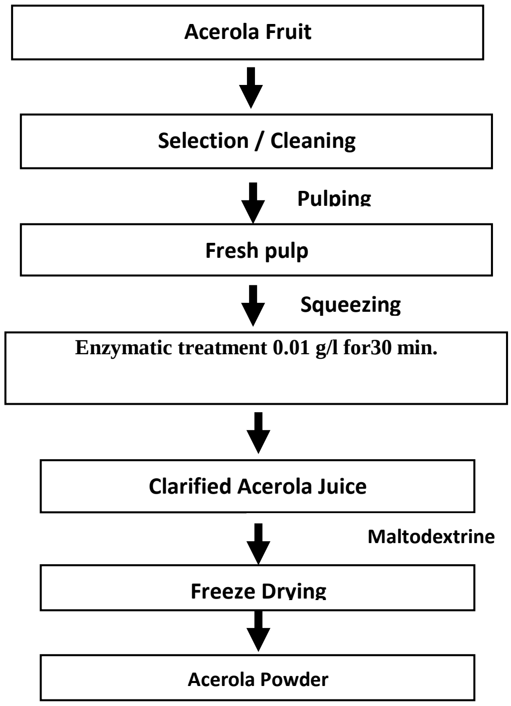

Fig. (3): Processing steps of freeze dried Acerola juice

Preparation of Annona juice:

Annona fruits were washed and then get rid of the outer peel. The seeds were manually removed and fruit puree was placed in a blender with water in ratio of 2: 1 (w/w) and blended twice. The pH and T.S.S were measured then pasteurized at 79 ° C for 69 second followed by rapid cooling, packaging and preserved by freezing as described by Umme, *et.al.*,(2001), as seen in Fig. (2).

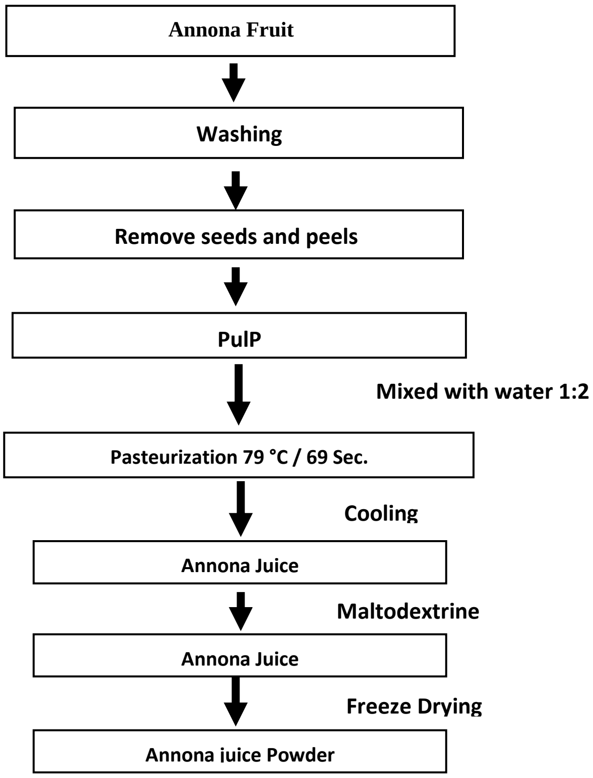

Fig.(2): Processing steps of freeze dried Annona juice

Acerola fruits were selected and cleaned. The fresh pulp was obtained by squeezing and pectinase enzyme 0.01 % was added and incubated for 30 min at 25°C then clarified. Maltodextrin was added to clarified acerola juice in a ratio of 1:5 and the juice was freeze dried as follows:

Freeze-drying was performed in a freeze drier (Labconco USA. temp collector -50°C) as described by Moβhammer *et al.*, (2006).The vacuum chamber total pressure and temperature were equal to 0.3 mbar and -30˚C, respectively. The thermocouple probe located at the bottom of the tray was used to control and monitor the product temperature. The sublimation heat was supplied by a heating plate located under the tray. During the secondary stage of drying, the product reached a final temperature of about 35˚C. Average freeze-drying time was approximately 12 hr.

Moisture, acidity and pH were determined according to A.O.A. C (2003).

Total soluble solids were determined by using refractometer at25°C and the results were expressed as ºBrix.

Apparent viscosity of different juices and reconstituted freeze dried powder were measured according to Ibarz *et al.*, (1994). A rotational viscometer (Rheotest, type RV2, Pruefgreate, Medingen, Germany) with measuring device (Z) of the cylinder S2 was used. Shear rate/ shear stress data of acerola, annona and cactus juice samples were subjected to mathematical modeling according to the power law model $\gamma = K.\gamma^n$

Where: t =shear stress (Dyne/cm^2)

K=consistency coefficient (Dyne.s^n/cm ^{2})

n=Flow behavior index (-)

γ= shear rate (s^{-1})

Annona pulp was diluted by water in ratio of 1:2 (pulp/water) to facilitate juice extraction and rheological measurements.

Statistical analysis :

All chemical and rheological experiments were carried out in triplicates and Statistically analysed. Mean values and significant differences were evaluated using SAS-package (2006) according to the method described by Gomez and Gomez (1976).

RESULTS AND DISCUSSION

Table (1) shows the major compenents of the obtained juices. The highest total solids was that of annona pulp (21.36 %), while those of cactus and acerola juices were in the range of 9.75 to12.34%.Samilar trend was also observed for the total soluble slids. On other side ,acerola and annona juices showed relatively high acidity (0.24 to 0.257%), and low pH values (3.18 and 4.98), while cactus juices contained a negligable amount of acidity (0.033 to 0.046 %). These data agree with those reported by Mercali *et al.*, (2013) for acerola,Ceballos *et al.*, (2012) for annona and Cassans *et al.*, (2010) for cactus juices.

Table 1 : Chemical composition of acerola, annona and Cactus Juices.

Parameter	Ac	An	Rca	Yca
Moisture	90.24^{a} ±0.19	78.63^{c}±0.19	87.66^{b} ±0.19	87.73^{b} ±0.19
T.S	9.75^{c} ±0.07	21.36^{a}±0.07	12.34^{b} ±0.07	12.26^{b} ±0.07
T.S.S	9.24^{c} ±0.07	17.3^{a}±0.07	10.48^{b} ±0.07	10.32^{b} ±0.07
pH	3.18^{c}±0.009	4.98^{b}±0.009	5.29^{a} ±0.009	5.33^{a}±0.009
Acidity (as citric acid)mg/100mL	0.240^{b}±0.002	0.257^{a}±0.002	0.033^{d} ±0.002	0.046^{c}±0.002

Ac : acrola juice An: annona juice Rca : Red cactus Yca : yellow cactus

Figures (4), (5), (6), (7) and (8) show the rheogrames of the tested juices, which were homogenized before being subjected to rheological test. The relationship between the applied shear rates and the corresponding shear stress responses were not linear indicating the non-Newtonian behavior of the juices obtained from acerola, annona, and cactus fruits. The magnitude of the obtained shear stress values varied according to the type of fruit and its composition Maximum shear stress response(at shear rate of 145.8s^{-1})were122.97 and 59.87 Dynes/$cm^2$for juices obtained from acerola and annona respectively. On other side, the juices of yellow and red cactus fruit recorded lower shear stress values at the same shear rate145. 8s^{-1}, being 27. 68 and 30. 75 Dynes/cm^2, respectively.

The differences in the levels of shear stress responses between the tested juices could be referred to the differences in the total solid contents, which contained different fiber levels . Enzymatic treatment of the tested juices prior to rheological tests has reduced their shear stress responses due to the splitting of macromolecular fibers, especially pectic substances , present in the raw juices. Fig. (6) Shows for example the rheograms of cactus juices before and after enzymatic treatment.

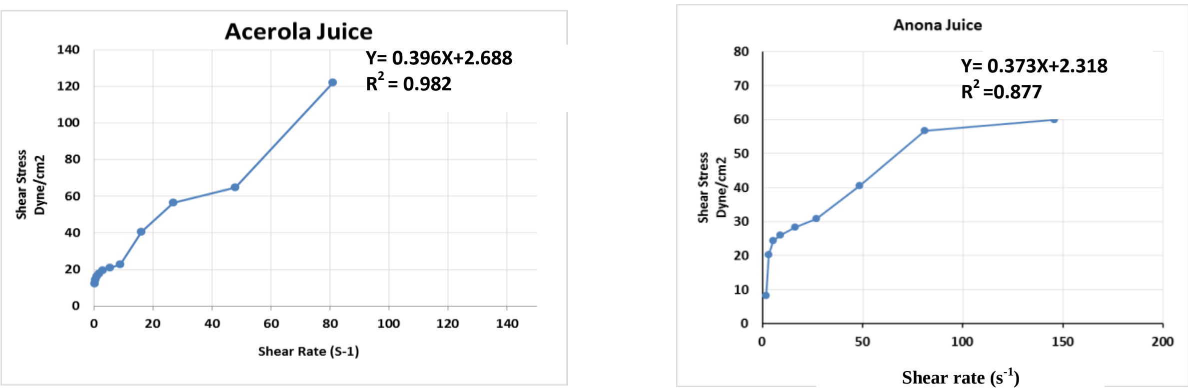

Fig. (4): Rheological characteristics of acerola and annona juices

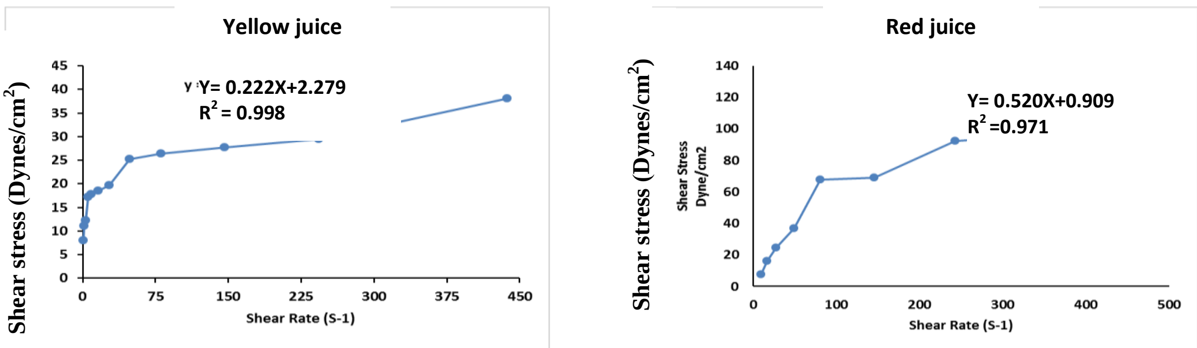

Fig. (5): Rheological characteristics of yellow and red cactus juice

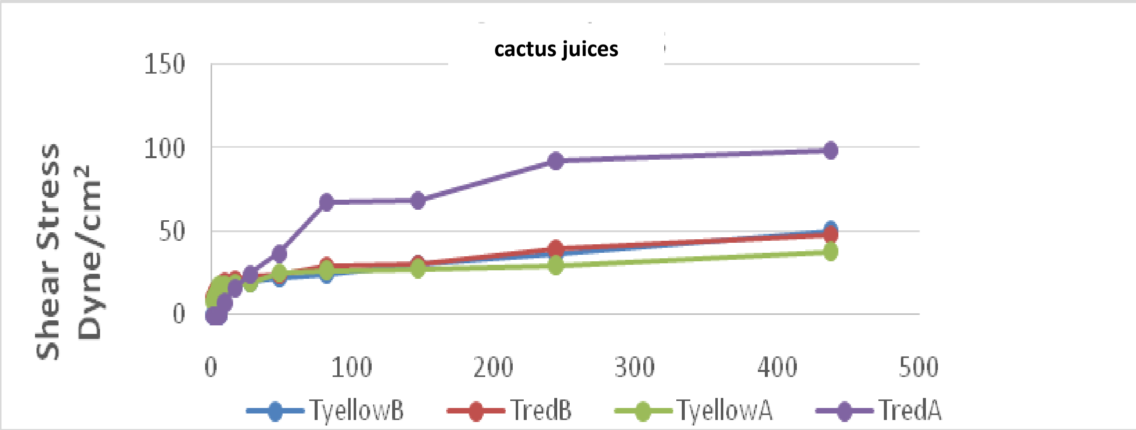

Fig. (6): Rheological characteristics of cactus juices before and after enzyme treatment

T Yellow B: Yellow before enzymatic treatment, T red B: Red before enzymatic treatment, T yellow A: Yellow after enzymatic treatment, T red A: Red after enzymatic treatment,

The shear rate/shear stress data of the tested juices were subjected to analysis according to power law equation and the flow parameters given in Table (2)

As seen, the n-value of tested juices was in the range of 0.222 to 0.520 indicating the strong non-Newtoniaty and pseudoplastic behavior of the tested fruit juices. The highest values of consistency coefficient (K-value) were recorded for acerola juice (14.70 Dynes.s^n /cm^2) and yellow cactus (before enzymatic treatment), which reached15.31Dynes.s^n/cm^2 Consistency coefficient values of diluted annona juice and untreated red cactus juices were 10.16 and11.03 Dynes.s^n/cm^2, respectively. As seen from Table (2) and Figure (6), enzymatic treatments of cactus juices are necessary to reduce their viscosities (expressed as consistency coefficient) and to prevent their gelling through the hydrolysis of their pectic substances.

Rheological characteristics of reconstituted juice from freeze- dried powders

Freeze dried powders of acerola; annona and cactus juices were reconstituted and homogenized to obtain reconstituted juices of 7% total solids. The juices were subjected to rheological analysis using a coaxial concentic rheometer as described before. The obtained rheograms are presented in Fig (7), (8), (9), and (10).

Table (2): Flow parameters of juices obtained from Acerola, Annona and cactus fruits

Parameters	Acerola juice	Annona juice	Yellow cactus Before enzymatic treatment	Yellow cactus After Enzymatic Treatment	Red cactus Before enzymatic Treatment	Red cactus After enzymatic Treatment
K (Dynes s^n/cm^2)	14.70	10.16	15.31	9.77	11.03	4.77
N	0.396	0.372	0.262	0.222	0.227	0.520
R^2	0.982	0.868	0.923	0.998	0.983	0.971

K: consistency coefficient   n: flow behavior index   AC: acerola juice   An: annona juice
Yca: yellow cactus juice   Rca: red cactus juice

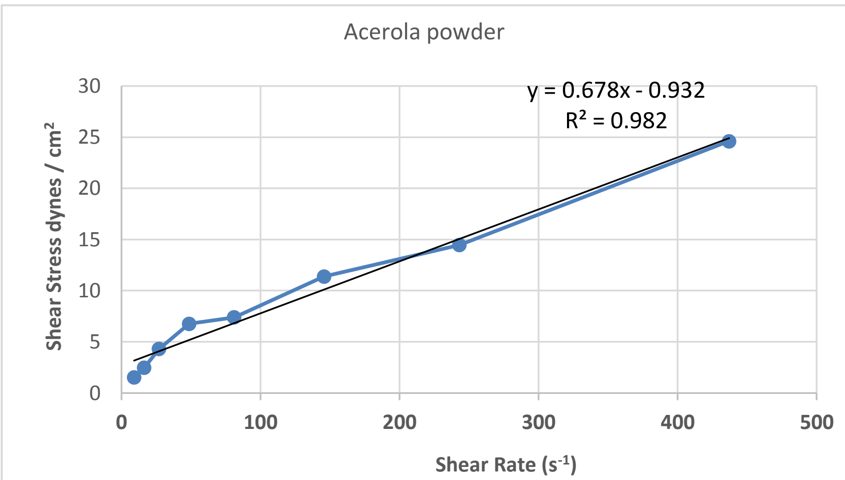

Fig. (7): Rheological characteristics of reconstituted acerola juice from freeze dried

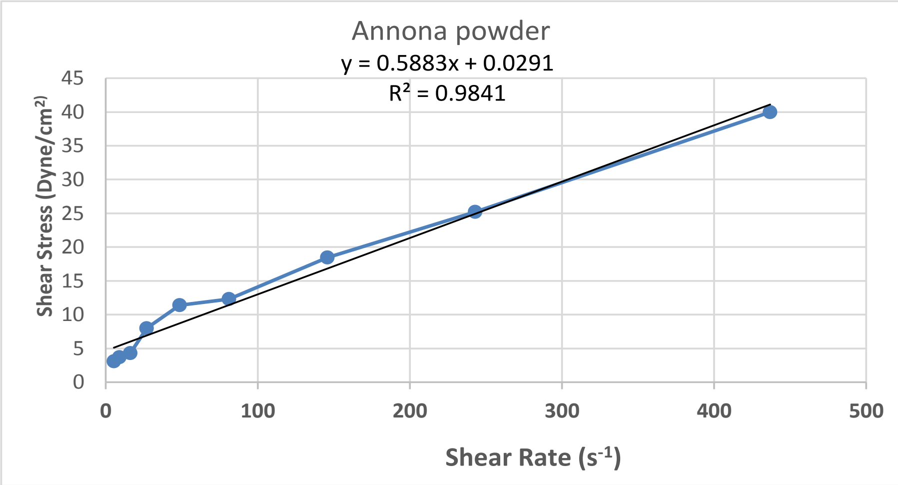

Fig. (8): Rheological characteristics of reconstituted annona juice from freeze dried

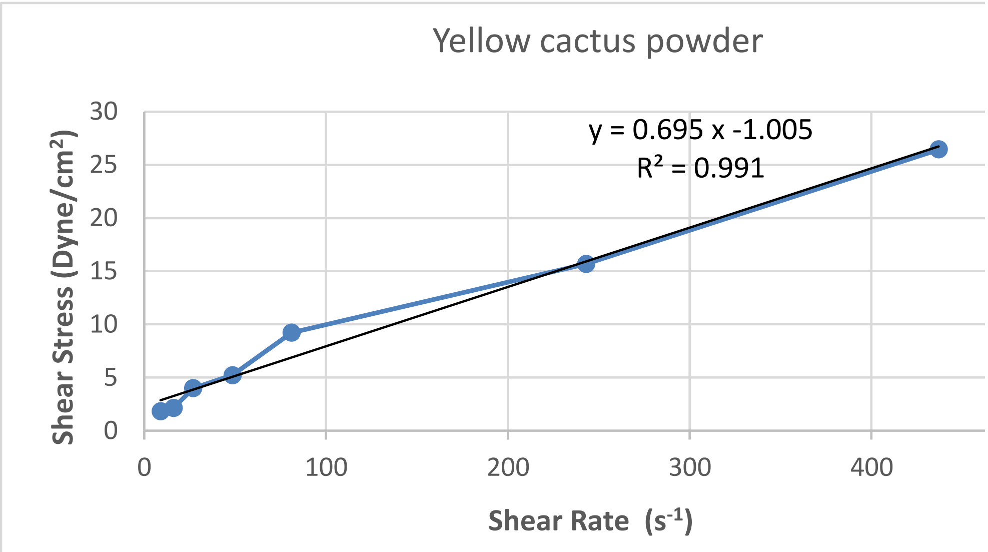

Fig. (9): Rheological characteristics of reconstituted yellow cactus juice from freeze dried

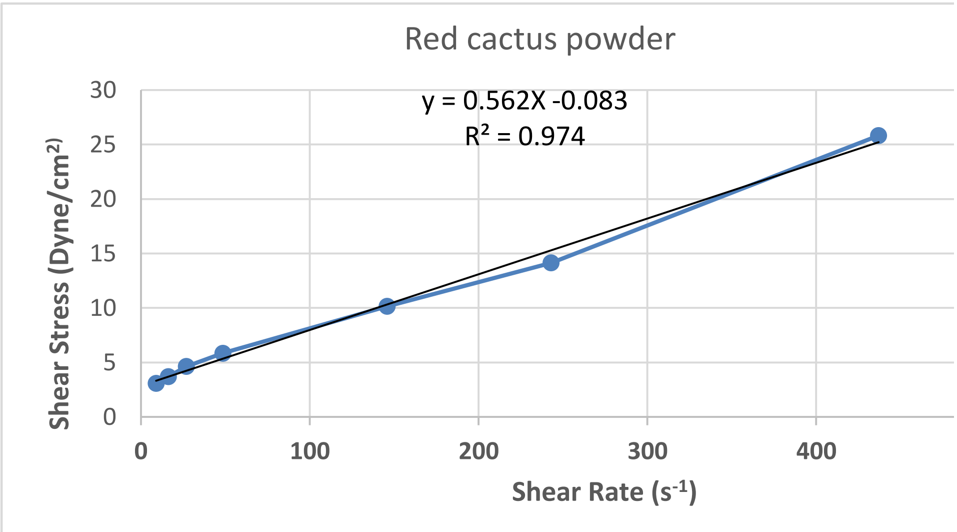

Fig. (10) Rheological characteristics of reconstituted red cactus juice from freeze dried

As seen, The magnitude of shear stress responses of the examined juices were much lower than the magnitude of shear stress values of their fresh juices at all applied shear rates.

For example, the shear stress responses of acerola juice at shear rate 81 $s^{-1}$was 122 and 7 dynes/cm^2 for fresh and reconstituted juices, respectively. The same trend was found for annona juices (56 and 9dynes/cm^2) as well as for red cactus juices (70 and 7 dynes/ cm^2).

The reason for such radical reduction in rheological behavior of freeze dried juices could be refered to the destruction of the colloidal system of the fresh juice by heat of drying and by removal of moisture content which destroy the hydrogen bonds between the macromolecules of colloidal system.

Table (3): Flow parameters of fruit juices obtained from reconstitute acerola, annona, and cactus powders.

Parameters	AC	An	Yca	Rca
K (Dynes s^n/cm^2)	0.394	1.030	0.366	0.9203
N	0.678	0.588	0.695	0.562
R^2	0.982	0.984	0.991	0.974

K: consistency coefficient n: flow behavior index AC: acerola juice reconstitute An: annona juice reconstitute Yca: yellow cactus juice reconstitute Rca: red cactus juice reconstitute

Table (3) shows the rheological parameters of the reconstituted juices. As seen, the magnitude of n-value as in the range of 0.562 to 0.695, being higher than their corresponding n-values of the fresh juices. Higher n-values mean less non- Nowtonianty and pseudo-plasticity of reconstituted juices compared with their fresh counterparners. At the same time, the obtained K-values of reconstituted juices were in the range of 0.366 to 1.030 dynes.s^n /cm^2, being much lower than the K-values reported for the corresponding fresh juices. However, reconstituted annona juice showed the highest K-value (1.030) dynes.s^n /cm^2 compared with those of acerola and cactus juices , which means that the reconstituted annona juice was more colloidal than those of acerola and cactus juices. The power law model proved to be suitable for describing the flow behavior of reconstituted juices, since the R^2–values were in the range of 0.974 to 0.991.The lower K-values and the relativity higher n-values of the reconstituted juices facilitate handling, pumping and thermal treatments during processing, filling and packaging of the final juices.

The obtained results agree with those of Da-Silva *et al* (2012) and Pereira *et al* (2014) for acerola juice; Gratao *et al* (2007) for annona juice as well as Yoon *et al* (2014) for cactus juice. They reported K-values of 14.4 to 20.8 dynes.s^n/cm^2 and n-values in the range of 0.35 to 0.42 for acerola juice with 7.5 to 9° Brix. They also reported a dynamic viscosity value of 70 dynes.s^n/cm^2 for cactus juice measured at a shear rate of $81s^{-1}$ and k-values of 11.9 to 15.8 dynes.s^n/cm^2 for 9.3°Brix annona pulp measured in the temperature range of 8.3°C to 28.4°C.

CONCLUSION

Nowadays, Acerola plants were introduced to Egypt through Horticulture research institute, Agriculture Research center in September,2003. Acerola is a potential crop in Egypt which has perfectly environmental conditions climate and soil appropriate for the acerola culture and also need to low water requirement, low labor input and low crops management. The obtained results indicated the suitability of this fruit for industrial processing and the obtained rheological parameters were help in proper design for equipment used in juice production lines.

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دراسات ريولوجية على العصائر الطازجة والمسترجعه من المسحوق المجفد من بعض الفواكه غير التقليدية

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تهدف الدراسة إلى تقييم الخواص الريولوجية للعصائر الطازجة والمسترجعه من المسحوق المجفد لبعض الفواكه غير التقليدية وهى الأسيرولا والقشطة والتين الشوكي الأحمر والأصفر على درجة حرارة ٢٥°م.اظهرت العلاقة بين معدل القص المستخدم Shear rate واجهاد القص shear stress علاقة غير خطية تتبع السلوك اللانيوتونى للعصائر المتحصل عليها من الأسيرولا والقشطة والتين الشوكي الأحمر والأصفر من النوع البلاستيك الكاذب.

وأوضحت النتائج أن أعلى قيمة للـ shear stress للأسيرولا تليها القشطة عند معدل قص قدره shear rate 145.8 s^{-1} كانت 122.97و59.87 داين/ سم٢على التوالى ومن ناحية أخرى سجلت عصائر التين الشوكي الأصفر والأحمر الطازجة أقل قيم للـ shear stress عند نفس قيمة معدل القص shear rate 27.68, 30.75 داين/ سم٢ على التوالي.

وطبقا لمعادلة power law equation فإنه تراوحت قيم (n-value) والتى تمثل دليل سلوك السريان للعصائر ما بين (٠.٥٢٠- ٠.٢٢٢) وهذا دليل على أن كل أنواع العصائر المختلفة تسلك سلوكا لانيوتونياً من النوع البلاستيك الكاذب Pesudoplastic behavior.

وكانت أعلى قيم لمعامل القوام (K) لعصير الأسيرولا ١٤.٧٠ (داين.ثانية^{ن}/ سم٢) بينما أقل قيمة كانت لعصير التين الشوكي الأحمر المعامل بالإنزيم ٤.٧٦٦(داين. ثانية^{ن}/ سم٢) وأعلى قيم لمعامل الارتباط لعصير التين الشوكي الأصفر (٠.٩٩٨) بينما أقل قيمة لعصير القشطة (٠.٨٦٨).

بينما تراوحت قيم الثوابت الريولوجية للعصائر المسترجعة من المسحوق المجفد بالنسبة لقيم (n) ما بين (٠.٥٦٢الى٠.٦٩٥) وكانت اكثر ارتفاعا مقارنتابالعصائر الطازجة وكانت أقل قيم للـ R^2 لعصير التين الشوكي الاحمر المسترجع وأعلى قيمة للـ R^2 كانت للعصير الأصفر (٠.٩٩١) وأوضحت الدراسة أن معامل القوام (K value) للعصائر المسترجعه سجلت أعلى قيمة كانت للعصير التين الشوكي الأصفر (٢.٧٣٣ داين.ثانية ^{ن}/ سم٢) بينما سجلت أقل قيمة لعصير القشطة المسترجع (١.٠٣٠ داين.ثانية ^{ن}/ سم٢).