Chemical and Rheological Characteristics of Orange-Yellow Cactus-Pear Pulp from Egypt

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ABSTRACT
Orange-yellow cactus-pear fruits from Egypt, called shameia variety, were collected at the same ripening stage from different regions to evaluate selected chemical properties and to study the rheological behavior of their pulps. The results obtained showed that there were differences between the pulp characteristics, which may be due to environmental effects. The fruits showed pulp ratios between 41.53% to 49.63%. All pulps had low acidity and high pH values ranging between 0.049% to 0.057% and 6.00 to 6.20, respectively. The rheological data obtained indicated that the flow behavior of all pulps was non-Newtonian besides exerting pseudoplastic behavior. Thixotropy values were 4.13 to 19.30 Pa s$^{-1}$; yield stress reached 2.26 N m$^{-2}$ at 20°C.

Key words: Cactus pear, Opuntia, pulp properties, Egypt

INTRODUCTION

Opuntia represents the largest and the most impressive member of the Cactaceae family. The genus Opuntia originates from Mexico and includes approximately 300 to 400 species and great number of varieties (Anaya-Perez, 2001; Benson, 1982; Odoux and Dominguez-Lopez, 1996; Stintzing and Carle, 2005). Prickly pear or cactus pear (Opuntia spp) is the most cultivated edible cactus crop in the world and is widely distributed in Mexico and the South American continent. It is also grown in many other regions of the world such as Africa, Australia, and the Mediterranean basin (Inglese et al., 2002; Mizrahi et al., 1997; Nobel, 1995; Piga, 2004). On the other hand, Opuntia ficus indica (L.) Miller is the most commonly known cactus that is grown for fruits, vegetable forage, and fodder (Pimienta-Barrios and Munoz-Urias, 1995; Rodriguez-Felix, 2002; Russell and Felker, 1987). Cactus-pear plants have two edible parts. First, there is the fleshy stem also known as cladode, cactus pad, cactus stem, nopalito (young pad), vegetable cactus, or cactus leaf (Rodriguez-Felix, 2002). Second, the fruits are highly appealing and nutritious.

Cactus-pear fruits are fleshy berries varying in shape, size, and color, and consisting of a thick peel hosting a delicately flavored juicy edible pulp with many hard seeds. The attractive color of both pericarp and pulp varies from a soft green, greenish-white, canary-yellow, orange-yellow, lemon- yellow, red, cherry-red to purple hues (Gurrieri et al., 2000; Munoz De Chavez et al., 1995; Saenz and Sepulveda, 2001). These attractive colors are due to the betalains comprising the red-violet betacyanins and the yellow-orange betaxanthins (Fernandez-Lopez and Almela, 2001; Odoux and Dominguez-Lopez, 1996; Saenz, 2002; Stintzing et al., 1999b, 2002). In contrast to anthocyanins, these colorants maintain their appearance over a wide pH range from 4 to 7, which makes them ideal pigments for coloring especially

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low-acid foods such as dairy products (Forni et al., 1992; Krifa et al., 1994; Montefiori, 1990; Saenz, 2000; Saenz et al., 1997; Stintzing et al., 2000).

The fruit pulp exhibits a high pH value (5.3 to 7.1), low acidity (0.01% to 0.18% as citric acid equivalents) and total soluble solids content ranging from 10.7° to 17°Brix, mainly due to reducing sugars (Abdel-Nabey, 2001; Askar and EL-Samahy, 1981; Barbagallo et al., 1998; Barbera et al., 1992; Gurrieri et al., 2000; Kuti, 1992; Parish and Felker, 1997; Piga et al., 2003; Russell and Felker, 1987; Saenz-Hernandez, 1995; Sawaya et al., 1983; Saenz and Sepulveda, 1999; Sepulveda and Saenz, 1999; Sepulveda et al., 2000). These characteristics make the pulp a very good medium for microbial spoilage (Saenz, 2000; Saenz and Sepulveda, 2001; Sepulveda and Saenz, 1990), but on other hand, very suitable to be added to low-acid foods such as ice cream and other dairy products. Sugar, protein, dietary fibers, and ash contents are similar to those of other fruits (Cantwell, 1995; Saenz-Hernandez, 1995 and Stintzing et al., 2001), but their high total amino acid contents, dominated by proline and taurine is a special feature of cactus fruits (Stintzing et al., 1999a, 2001). The pulp is a good source of vitamin C, calcium, and magnesium, in addition to pectin and mucilaginous components (complex ploysaccharides, mainly composed of arabinose, galactose, rhamnose, and galacturonic acid) that influence the pleasant flavor of pulp and could serve as thickening agents and form viscous colloids (Piga, 2004; Saenz et al., 1992; Stintzing, et al 2001).

Recent data indicate that cactus-pear pulp has multiple functional properties and could be a good natural source of nutraceuticals (Saenz, 2002 and Stintzing et al., 2000, 2001), such as vitamin C, betalains, phenolics, and taurine (Kuti, 2004; Piga et al., 2003; Piga, 2004). Moreover, cactus-pear pulp is rich in taurine, a conditional essential nonproteinogenic amino acid widely distributed in many animal food sources, except cow milk, but virtually absent in higher plants, especially fruits (AACE, 2003; Kindler, 1989; Parcell, 2002; Stintzing et al., 1999a).

Prickly pear fruits usually eaten fresh after peeling could be processed into many different products such as juices, nectars, dehydrated sheets, marmalades, jellies, jams, natural sweeteners, wines and other alcoholic beverages, candies, canned and frozen fruit, etc. (Abdel-Nabey, 2001; Barbera, 1995; Gurrieri et al., 2000; Hoffmann, 1995; Saenz, 2000; Saenz-Hernandez, 1995; Saenz and Sepulveda, 2001; Saenz et al., 1998).

Notably, the rheological properties of cactus-pear pulp are virtually unknown except in data presented by Saenz (2000) who indicated that the viscosity of green and purple cactus-pear pulps amounted to 73.9 and 110.2 mPa s, respectively, and El-Samahy et al. (2006b) who showed that the flow behavior of cactus-pear pulp is non-Newtonian, beside being pseudoplastic in behavior with the presence of thixotropy. Thixotropic materials can be defined as those that exhibit decreasing shear stress and apparent viscosity over time at a fixed rate of shear, this action may be irreversible, reversible, or partially reversible (Steffe, 1996). Knowledge of the rheological properties of fruit pulps is essential for the design of food processing equipment as well as for application of such products in foods (El-samahy et al., 2003, 2004a, 2004b).

In Egypt, prickly pears have been grown for many years, especially in arid areas. The Opuntia plants are grown not only for fruit production but also as defensive hedges or for erosion control in reclaimed areas. In recent years, the production of prickly-pear fruits increased as a result of an increase in producing area. The producing area increased from about 617.82 hectares in 1994 to 1115.52 hectares in 2004 with a corresponding production increase from 10233 to 29610 Tons (MALR, 1994, 2004).
MATERIALS AND METHODS

Plant Material

*Prickly-Pear Fruit Samples*
Representative fruits of orange-yellow prickly-pear cactus fruits, called shameia variety, were collected from three different specialized orchards at the same ripening stage (half ripening) at the end of July. Figures 1 through 5 show examples of the cladode form, fruits, and plantations. The orchards were located in three different regions: Al Sharqiyah, Al Qalyubiyah, and Al Isma'iliyah. For each orchard three samples (80 fruits for every sample) were selected randomly from 240 representative fruits. All selected fruits were washed, manually peeled, and blended for 5 seconds in a blender (Moulinex, type 241, code 222, France) just to facilitate the separation of the seeds, and then the full pulps were sieved to separate only the seeds. The resultant pulp samples contained all their components and were tested freshly for all analyses.

*Environmental Conditions of the Orchard Regions*
The most effective difference between the orchards regions is the nature of the soil. Whereas the orchard of Al Sharqiyah region has a loamy soil, the other orchards (Al Qalyubiyah, and Al Isma'iliyah regions) have a sandy soil.

*Climatic Conditions of the Regions*
The annual average precipitation is about 40 mm for the Al Sharqiyah and Al Isma'iliyah regions and is about 20 mm for the Al Qalyubiyah region. The rainy season extends from December to February for all regions. The three fields are irrigated by flood from the same water source, a grand water canal branched from the Nile River. The averages of maximum and minimum temperatures and maximum and minimum relative humidity values of air during July are at Al Sharqiyah region (33.8º, 23.8º, 79% and 41%), Al Qalyubiyah region (33.6º, 21.8º, 91% and 40%), and Al Isma'iliyah region (30º, 22.1º, 83% and 30%), respectively (according to data of the Agricultural Researches Center, Ministry of Agriculture and Land Reclamation, Egypt).

*Assessment of Chemical Quality Parameters*
Chemical analyses were carried out according to AOAC (1990). Color attributes ($L^*$, $a^*$ and $b^*$) were evaluated using a Minolta Color Reader CR-10 (Minolta Co. Ltd., Tokyo, Japan).

*Rheology*
Rheological properties of all pulps were determined at different temperatures within the range of 5 to 90ºC by a Brookfield Digital Rheometer model DV-III+ (Brookfield, Middleboro, USA). The Brookfield small sample adapter and Sc4-14 spindle were used. The data were analyzed by using the Bingham plastic, IPC paste and Power Law mathematical models to provide a numerical and graphical analysis of the behavior of data sets (Hegedusic et al., 1995). These models are:

$$\tau = \tau_0 + \eta \gamma , \quad \eta = K \gamma^\alpha , \quad \tau = K \gamma^\alpha ,$$

respectively.

Where:
- $\tau$ = shear stress (N m$^{-2}$)
- $\tau_0$ = yield stress, shear stress at zero shear rate (N m$^{-2}$)
- $\eta$ = plastic viscosity (mPa s) for Bingham and 10 rpm viscosity (mPa s) for IPC paste
\( \gamma \) = shear rate (s\(^{-1}\))

K = consistency multiplier (mPa s) for IPC paste and

K = consistency index (mPa s) for Power Law

R = rotational speed (rpm)

n = shear sensitivity factor for IPC paste and flow index for Power Law.

Calculation of thixotropy was based on measuring, according to spindle type and rotational speeds, the shear rate (up curve) and also registering the same parameter using the reverse direction (down curve), the area between the ascending and descending curves, i.e., hysteresis was quantified using a planimeter according to Lozano and Ibarz (1994), this area is given in Pa s\(^{-1}\).

**Statistical Analysis**

The analysis of variance (ANOVA) was carried out to test the possibility of significance of treatment effect. LSD, as described by Ott (1984), was used to perform all possible pair comparisons between means of different treatments.

**RESULTS AND DISCUSSION**

**General Composition Of Cactus-Pear Fruits**

Table 1 shows that the fruits of the three regions varied significantly in fruit weight and in each of the pulps, peels, and seeds percentages. Fruits of the Al Sharqiyyah region were significantly higher in fruit weight and pulp content but lower in peels and seeds percentages. The differences may be due to the nature and, consequently, the fertility of the soil. The orchard of Al Sharqiyyah region has a loamy soil while the other regions have a sandy soil. The values obtained agreed with those obtained by others (Abdel-Nabey, 2001; Barbera et al., 1992; Cantwell, 1995; Karababa, 2004; Parish and Felker, 1997; Piga, 2004; Sawaya et al., 1983; Stintzing et al., 2005).

**Chemical Composition Of Cactus-Pear Pulps**

In concordance with data obtained by others (Abdel-Nabey, 2001; Askar and EL-Samahy, 1981; Cantwell, 1995; Parish and Felker, 1997; Saenz-Hernandez, 1995; Saenz and Sepulveda, 1999; Sawaya et al., 1983; Sepulveda and Saenz, 1999), Egyptian cactus-pear pulps were characterized by a high pH, a low acidity, and good contents of sugars, proteins, crude fibers, pectin, ash, and vitamin C (Table 2). The chemical composition of cactus-pear pulps appeared to be similar to some other fruit pulps, but could be higher than some other fruit pulps, such as guava pulp, in sugar content. These unique characteristics in addition to its attractive color make the cactus-pear pulps sweeter and very suitable to be a good natural food or natural-food additive with many categories of foodstuffs. However, the high soluble solids, high pH values, and low acidity of all investigated pulps present a great challenge to processing of cactus-pear pulps. More wariness is required during processing because these characteristics make the pulp a very good medium for spoilage due to microbial activity.

**Rheological Properties of Cactus-Pear Pulps**

Table 3 shows that the relationship between shear stress (\( \tau \)) and shear rate for all cactus-pear pulps were nonlinear, which related to non-Newtonian behavior in addition to the presence of thixotropy. The data
obtained showed that cactus-pear pulp is a pseudoplastic liquid with yield stress like many other fruit pulps and purees such as mango pulp (Bhattacharya, 1999), strawberry pulp (Bahlol, 2000), and peach and papaya purees (Guerrero and Alzamora, 1998).

The results showed that the pulp extracted from Al Isma’iliyah fruits had higher k, η, and 10-rpm viscosity values than those for pulp extracted from Al Sharqiyah and Al Qalyubiyyah fruits at the same temperature (20°C). The flow-behavior index (n) values ranged from 0.35 to 0.38 at 20°C for the pulp of the three regions’ fruits. The pulp extracted from Al Sharqiyah fruits had the highest value of yield stress 2.26 N m\(^{-2}\). These differences may be attributed to the specific chemical composition of the fruit pulps Table 2, especially nonsoluble materials, acidity, and total soluble solids (El-Samahy et al., 2006b).

Because the thixotropy term refers to the time-dependent decrease in viscosity, due to shearing, and the subsequent recovery of viscosity when shearing is removed (Mewis, 1979), and is used to describe a reversible isothermal gel-sol-gel transformation (Kramer and Twigg, 1984; Steffe, 1996), cactus-pear pulp is a thixotropic material. Thixotropy values of the pulp extracted from Al Sharqiyah fruits were higher than those from Al Qalyubiyyah and Al Isma’iliyah fruits, whereas 19.30 Pa s\(^{-1}\) was found for Al Sharqiyah fruit pulp and 12.87 and 4.13 Pa s\(^{-1}\) were registered for Al Qalyubiyyah and Al Isma’iliyah pulps, respectively, at 20°C.

Moreover, values of all studied parameters, except flow-behavior index and plastic viscosity, decreased with increasing temperature for the pulp extracted from different fruits up to 50°C. At higher than 50°C, all values of studied parameters increased, while the flow index and plastic-viscosity values decreased. These results agree with those obtained by Crandall et al. (1982), El-Samahy et al. (2006b), Ibraz and Pagan (1987), and Juszczak and Fortuna (2003). Van Buren (1991) reported that the differences in pectin fractions must be taken into account because polymer interactions play the major role in flow behavior of the fruit products. Goycoolea and Cardenas (2003) reported that pectins of cactus pear do not form gels and only increase the viscosity of the solutions. In addition to the influence of temperature and dissolved solids on viscosity of juices (Bayindirli, 1992), we suggest that the changes we observed in flow behaviour may also be attributable to changes in the colloid state of the pulp components (especially pectins) that are, in turn, influenced by acidity, sugars, and bivalent cations such as Ca\(^{2+}\).

**CONCLUSION**

This investigation shows the potential value of cactus-pear fruits as a good natural source of energy, nutritive components, and antioxidants such as vitamin C. Based on its low acidity, high sweetness, and attractive stable colors, cactus-pear pulp could be very suitable as a natural additive or substituted material in the production of many foodstuffs. Cactus-pear pulp is a non-Newtonian liquid that has pseudoplastic behavior with the presence of thixotropy and yield stress. The rheological properties are important factors, especially in the relation between the manufacturing process and product acceptance, and correlate with food composition and organoleptical properties. There is a need to do more research on the rheological properties of cactus-pear fruits, especially in the areas in the world that have rapidly increasing production of *Opuntia ficus-indica* fruits.
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Figure 1. Cactus-Pear Cladode

Figure 2. Orange-yellow cactus-pear fruits

Figure 3. Internal Longitudinal Section of Fruit

Figure 4. Overview of Cactus-Pear Plant

Figure 5. Overview of Cactus-Pear Field
### Table 1. General Composition of Cactus-Pear Fruits

<table>
<thead>
<tr>
<th>Property</th>
<th>Al Sharqiyah</th>
<th>Al Qalyubiyah</th>
<th>Al Isma'iliyah</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fruit weight (g)</td>
<td>133.50&lt;sup&gt;a&lt;/sup&gt;</td>
<td>120.57&lt;sup&gt;b&lt;/sup&gt;</td>
<td>110.19&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Pulp (%)</td>
<td>49.63&lt;sup&gt;a&lt;/sup&gt;</td>
<td>42.28&lt;sup&gt;b&lt;/sup&gt;</td>
<td>41.53&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Peels (%)</td>
<td>39.23&lt;sup&gt;b&lt;/sup&gt;</td>
<td>45.37&lt;sup&gt;a&lt;/sup&gt;</td>
<td>44.53&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Seeds (%)</td>
<td>11.14&lt;sup&gt;c&lt;/sup&gt;</td>
<td>12.35&lt;sup&gt;b&lt;/sup&gt;</td>
<td>13.80&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

- Means of triplicates
- Means having the same letter within each property are not significantly different at p ≤ 0.05

### Table 2. Some Technological and Chemical Properties of Cactus-Pear Pulps

<table>
<thead>
<tr>
<th>Property</th>
<th>Plantation Region</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Al Sharqiyah</td>
</tr>
<tr>
<td>pH value</td>
<td>6.20&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Acidity (%)</td>
<td>0.049&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>TSS (°Brix)</td>
<td>13.50&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Vitamin C (mg 100 g&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>21.50&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Formol number (mg 100 g&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>21.50&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Color attributes</td>
<td></td>
</tr>
<tr>
<td>L&lt;sup&gt;*&lt;/sup&gt;</td>
<td>30.60&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>a&lt;sup&gt;*&lt;/sup&gt;</td>
<td>1.60&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>b&lt;sup&gt;*&lt;/sup&gt;</td>
<td>10.90&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Moisture (%)</td>
<td>86.27&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>TS (%)</td>
<td>13.73&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Total Sugars (%)&lt;sup&gt;*&lt;/sup&gt;</td>
<td>88.02&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Reducing sugars (%)&lt;sup&gt;*&lt;/sup&gt;</td>
<td>85.24&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>AIS (%)&lt;sup&gt;*&lt;/sup&gt;</td>
<td>7.10&lt;sup&gt;b&lt;/sup&gt;</td>
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<td>Protein (%)</td>
<td>4.59&lt;sup&gt;b&lt;/sup&gt;</td>
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<td>Pectin (%)</td>
<td>2.39&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Fiber (%)&lt;sup&gt;*&lt;/sup&gt;</td>
<td>1.40&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Ash (%)&lt;sup&gt;*&lt;/sup&gt;</td>
<td>2.39&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Sugar/acidity ratio</td>
<td>246.6&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

* Calculated on dry-weight basis
- Means of triplicates
- Means having the same letter within each property are not significantly different at p ≤ 0.05
Table 3. Rheological Properties of Cactus-Pear Pulps

<table>
<thead>
<tr>
<th>Plantation Region</th>
<th>Temp. °C</th>
<th>Parameters for Different Rheological Models</th>
<th>Thixotropy Pa s⁻¹</th>
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<tr>
<td></td>
<td></td>
<td>Power law</td>
<td>Bingham</td>
</tr>
<tr>
<td></td>
<td></td>
<td>k</td>
<td>n</td>
</tr>
<tr>
<td>Al Sharqiyah</td>
<td>5</td>
<td>147.7</td>
<td>0.31</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>146.9</td>
<td>0.32</td>
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<td></td>
<td>20</td>
<td>137.6</td>
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<tr>
<td></td>
<td>30</td>
<td>134.8</td>
<td>0.31</td>
</tr>
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<td></td>
<td>40</td>
<td>90.3</td>
<td>0.35</td>
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<tr>
<td></td>
<td>50</td>
<td>96.9</td>
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</tr>
<tr>
<td></td>
<td>60</td>
<td>134.4</td>
<td>0.33</td>
</tr>
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<td></td>
<td>70</td>
<td>246.3</td>
<td>0.19</td>
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<td></td>
<td>80</td>
<td>352.0</td>
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</tr>
<tr>
<td></td>
<td>90</td>
<td>482.4</td>
<td>0.01</td>
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<tr>
<td>Al Qalyubiyyah</td>
<td>5</td>
<td>92.9</td>
<td>0.33</td>
</tr>
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<td></td>
<td>10</td>
<td>87.6</td>
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<td></td>
<td>20</td>
<td>84.3</td>
<td>0.38</td>
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<td></td>
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<td>52.2</td>
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<td>50</td>
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<td>0.43</td>
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<td>65.2</td>
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<td></td>
<td>70</td>
<td>78.8</td>
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<td></td>
<td>80</td>
<td>115.9</td>
<td>0.20</td>
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<tr>
<td></td>
<td>90</td>
<td>206.0</td>
<td>0.05</td>
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<tr>
<td>Al Isma‘iliyyah</td>
<td>5</td>
<td>174.2</td>
<td>0.30</td>
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<td></td>
<td>10</td>
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<td>142.4</td>
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<td>79.3</td>
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<td>90.3</td>
<td>0.39</td>
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<td></td>
<td>80</td>
<td>115.9</td>
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</tr>
<tr>
<td></td>
<td>90</td>
<td>344.5</td>
<td>0.02</td>
</tr>
</tbody>
</table>

K = Consistency index (mPa s), n = Flow index (dimensionless), η = Plastic viscosity (mPa s), τ₀ = Yield stress (N m⁻²), 10 rpm viscosity, (mPa s), N₁ = Shear sensitivity (dimensionless)