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DRAG REDUCTION BY BIOPOLYMERS - INFLUENCE OF OKRA VARIETY AND MATURITY INDEX ON ADDITIVE EFFICIENCY

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Abstract. *Drag reduction by the addition of polymers is a simple and inexpensive method to increase the efficiency of hydraulic transport. Recent concerns with the environment lead to the need to replace conventional synthetic polymers with natural polymers, which do not generate negative impacts on nature. One of the proposed biopolymers is okra (Abelmoschus esculentus), which physicochemical characteristics are affected by plant variety and fruit maturity, among other parameters. Thus, the objective of this work is to analyze the efficiency of three plant varieties (Amarelinho, Clemson and Santa Cruz) on the efficiency of the additive used as drag reducing agent. The influence of the harvest period was also evaluated for the latter variety. All the samples obtained were characterized chemically and rheologically and the drag reduction tests were carried out in a flow loop apparatus. The results show that although there are no significant differences according to the cultivar analyzed, the maturity of the fruits can considerably influence the efficiency of the biopolymer as drag reducer.*

Keywords: *drag reduction, turbulence, biopolymer, okra, Abelmoschus esculentus.*

1. INTRODUCTION

The term drag reduction (DR) refers to a method to increase the efficiency of turbulent systems by reducing tangential and dissipative forces. The first report of this phenomenon is attributed to Toms (1948), who discovered through experiments that the inclusion of a small amount of polymers at turbulent flows could reduce the head loss. Since then, this method has been used to improve the transport of fluids in various applications, being responsible for increasing the reach of hoses used in firefighting systems (Fabula, 1971) and the flow of oil in pipelines (Burger *et al.*, 2013). In both cases, synthetic polymers are used, which, despite proven efficiency, have inconveniences due to toxicity and generation of waste that harm the environment.

Recent efforts are focused on obtaining natural polymers, which are cheaper, biodegradable and non-toxic, making it possible to use them in medical and agricultural areas.

Among the biopolymers already described in the literature, okra (*Abelmoschus esculentus*) stands out for its low cost and ease of processing, as reported by Abdulbari *et al.* (2011) and Coelho *et al.* (2016). In these works, the authors acquired the fruits in the local commerce, according to availability, but there is evidence that factors like fruit maturity and plant variety can influence the physicochemical characteristics of okra (Mota *et al.*, 2005 and Noorlaila *et al.*, 2015). Therefore, it is pertinent to evaluate how these parameters can affect the efficiency of okra as a reducing agent.

In this work, the behavior of three different varieties of okra as drag reducing agents is investigated (Amarelinho, Clemson and Santa Cruz) by experimental tests. In addition, we intend to analyze the influence of the fruit maturation index on the biopolymer action, using vegetables of the Santa Cruz cultivar harvested at 7, 12 and 15 days. In order to guarantee the minimal influence of external variables, such as cultivation location and processing method, all stages of the process were controlled, from planting the okra plants to the execution of the experiments.

2. METODOLOGY

The different steps for the development of this work can be divided into six parts: seeds planting and plants cultivation, biopolymer production, chemical characterization, solution preparation, rheological characterization and drag reduction tests. The procedures used in each part will be described in the subsequent sections.

2.1 Seeds planting and plants cultivation

Seeds of Amarelinho, Clemson Spinless and Santa Cruz okra, all from "Isla Sementes", were planted following the producer's instructions: pits of 2 cm depth and plant spacing of 50 cm, approximately. The sowing was carried out in the north of Espírito Santo, where the tropical climate favors the growth of okra during the whole year. The soil was enriched with bovine manure and irrigated manually once a day. The first harvest was done manually at 50 days (Clemson) and 70 days (Amarelinho and Santa Cruz) after planting, 7 days after the appearance of the flowers. For tests related to the maturation period, the fruits were also collected within 12 and 15 days. To avoid the material's decomposition, the collected fruits were stored in the refrigerator for about 24 hours until the next step was possible.

2.2 Biopolymer production

The reducing agent is a powder composed of a mixture of okra's fiber and mucilage, as proposed by Coelho *et al.* (2016). Therefore, the procedure described by the authors was adopted to obtain the additive. The okra pods were first washed and their tips removed with a knife. Next, the fruit was cut to remove the seeds with a spatula. The remaining material went to a 50 °C oven to speed the drying process without compromising its thermolabile properties, as reported by Lee *et al.* (2015). This step was completed when the vegetable achieved a constant mass. Finally, the dehydrated okra was grinded in a blender and the granulometry of the product controlled by sieves. Although the granulometry used by Coelho *et al.* (2016) was thinner than 106 µm, in this paper we also tested a thicker powder, which was retained between the 106 µm and 1 mm sieves, in order to avoid part of the energy input required to control the grain size. Some of the steps in this process can be identified in Fig. 1.


(a) Okra pods.


(b) Sliced okra.


(c) Okra pods without seeds.


(d) Dehydrated okra.


(e) Okra powder (thick powder on left, thin powder on right).

Figure 1. Steps of okra processing.

2.3 Chemical characterization

The differences in the chemical composition of the specimens analyzed lead to the hypothesis that their action as a reducing agent could be also different. The technique employed for chemical characterization was infrared spectroscopy (FTIR), which according to Dias *et al.* (2016) allows identifying qualitatively and quantitatively the presence of chemical groups in a sample, since it is based on the principle that each class of chemical components emits radiation at a specific frequency. The result of the analysis consists of a graph with several peaks in different frequency bands.

Through the analysis, the position of the signal (chemical shift) can be related to a certain chemical group. In addition, the magnitude of the peak is proportional to the relative amount of the component present in the sample. The results of this step will be presented in the final paper.

2.4 Solution preparation

Diluting the powder produced in the previous step in filtered water produced solutions of each variety and maturity index of okra in the concentrations of 100 ppm and 200 ppm. The concentration was calculated using Eq. (1).

$$c = \frac{m_{solute}}{m_{solution}} \tag{1}$$

Where: c is the solution's concentration, m_{solute} is the solute mass and $m_{solution}$ is the solution mass.

2.5 Rheological characterization

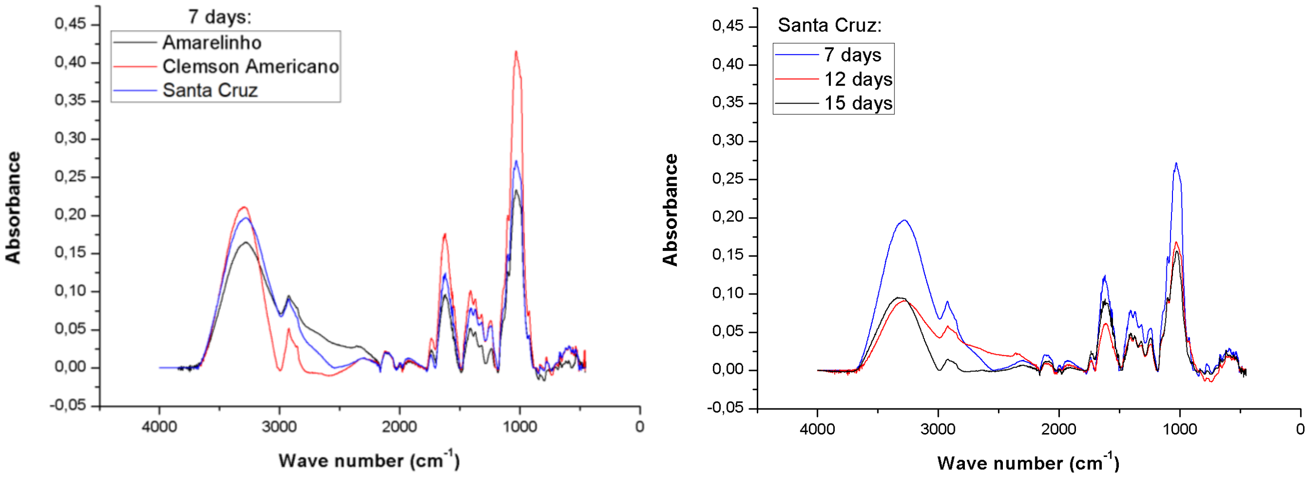
For the determination of the solutions rheological properties, a commercial rheometer with concentric double-gap geometry was used, equipped with a thermostatic bath to guarantee precise temperature control. The data was acquired via a computer connected directly to the equipment.

2.6 Drag reduction tests

For the drag reduction experiments, a flow loop that simulates a long pipe through the number of passes was used. 100 liters of okra's solution was prepared in a reservoir and drained to a pressure vessel by gravity. A centrifugal pump was responsible for boosting the contents of the vessel through the hydraulic circuit, which was 13.5 meters long. Along this region, an electromagnetic flow meter and three static pressure transducers were coupled so that the drag reduction could be indicated in terms of the decrease in pressure drop and increase in flow rate.

3. RESULTS

At first, chemical characterization was performed. The results are shown in Fig. 2, for different varieties and maturity indices.



(a) Varieties Amarelinho, Clemson and Santa Cruz. (b) Maturity indices: 7, 12 and 15 days.

Figure 2. Okra spectra produced by chemical characterization.

In Figure 2, the noticeable peaks are in the same zones, independent to the variety or maturity index. The bands in 3600-3000 cm^{-1}, 1850-1600 cm^{-1} and around 1000 cm^{-1} are characteristic of carbohydrates, proteins and lipids; the band in 2700-2100 cm^{-1} refers to minerals. The peak in 3000-2800 cm^{-1} is common to all organic compounds. This composition agrees to the described by Iwu (2014) for okra: carbohydrates, proteins, lipids and minerals.

The main difference between the spectra is their heights (absorbance), related to the quantity of the substances in the samples. Thus, according to Fig. 2(a), it is expected to Clemson to have more carbohydrates, proteins and lipids, followed by Santa Cruz and then Amarelinho, which seems to have more minerals than the other cultivars. Coelho *et al.*

(2016) reported that the drag reduction is most caused by carbohydrates and proteins (natural polymers), so probably Clemson and Santa Cruz okras are better drag reducing agents than Amarelinho. Regarding to the maturity index in Fig. 2(b), the younger okra (harvested in 7 days) have a greater amount of polymers than the older fruits.

The shear viscosity of the drag reducing solutions was measured via rheometer. Figure 3 shows the results for 100 ppm concentration of the three cultivars analyzed.

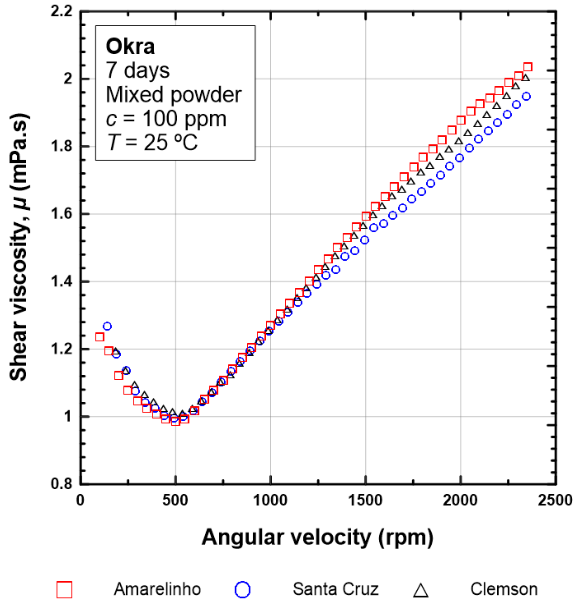


Figure 3. Shear viscosity of different okra varieties' solutions (c = 100 ppm).

In Figure 3, there are two different behaviors of the shear viscosity influenced by the angular velocity increase. The first segment refers to laminar flow, where viscosity decreases with the increasing angular velocity; the second one, after 500 rpm, refers to turbulent flow and the viscosity increases when the rotation is increased. The solution's viscosity is measured in the inflection point and it's almost the same value for all three varieties, also it is similar to water viscosity at this temperature. Analogous results were observed to 200 ppm solutions, regardless to varieties or maturity indices. It demonstrates that small concentrations of polymers diluted in water are not sufficient to modify solvent's properties, as described by Coelho *et al.* (2016).

Regarding to drag reduction experiments, tests were carried out for the flow loop validation by comparison of Darcy friction factor caused by filtered water flowing through the system with Blasius Lawm as showed in Fig. 4.

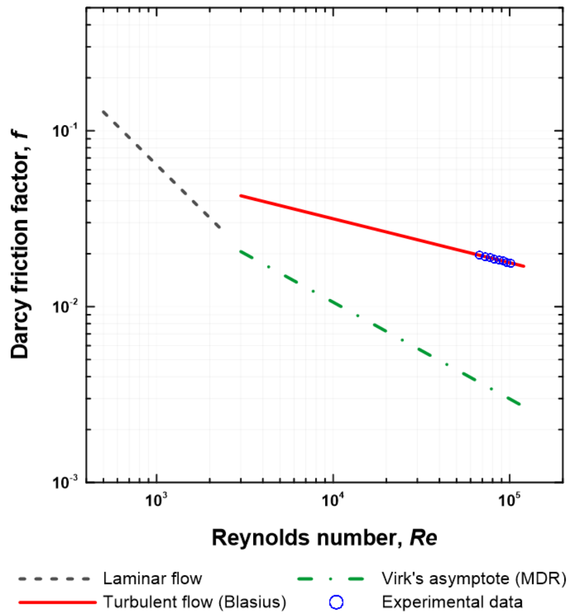


Figure 4. Validation of flow loop.

Compared to the expected behavior predicted by Blasius Equation, the maximum error in Fig. 4 was around 3%, which is also comparable to other works performed in the same equipment (Coelho *et al.*, 2016 and Barbosa, 2017). Thus, it was considered that the flow loop provides results with sufficient accuracy.

Another preliminary test was the verification of repeatability. In this test, using two different samples of Santa Cruz's 200 ppm solution, the maximum error was about 1,8%, which indicates a sufficient precision of the apparatus.

As described in section 2.2, it was decided to use part of a thicker powder as drag reducer. The effects of powder granulometry on DR are shown in Fig. 5 for Santa Cruz okra harvested in 7 days.

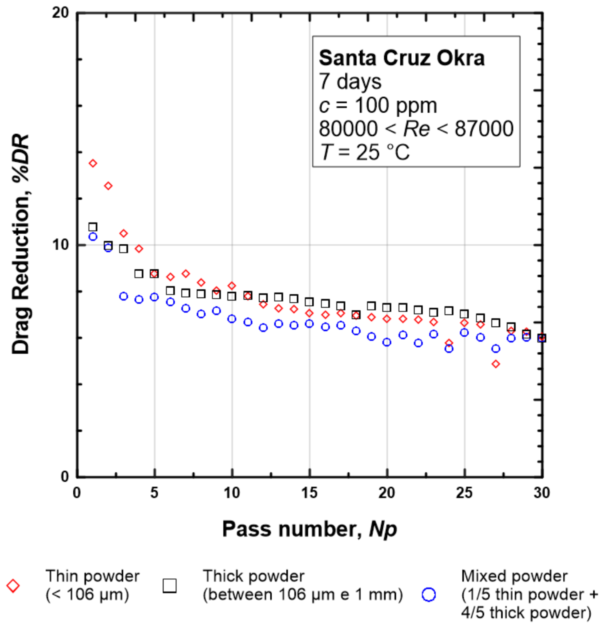


Figure 5. Effect of the okra's powder granulometry on drag reduction.

According to Fig. 5, there was no great discrepancy between the drag reduction for the different granulometries analyzed, it was decided to continue the other experiments using what will be called as "mixed powder", consisting of 20% of thin powder (smaller than 106 μm) and 80% of the thick powder (between 106 μm and 1 mm). It made possible to save more material, decreasing production time and energy use.

The differences of the okra cultivars as drag reducing agents were evaluated for the concentrations of 100 ppm and 200 ppm (Fig. 6).

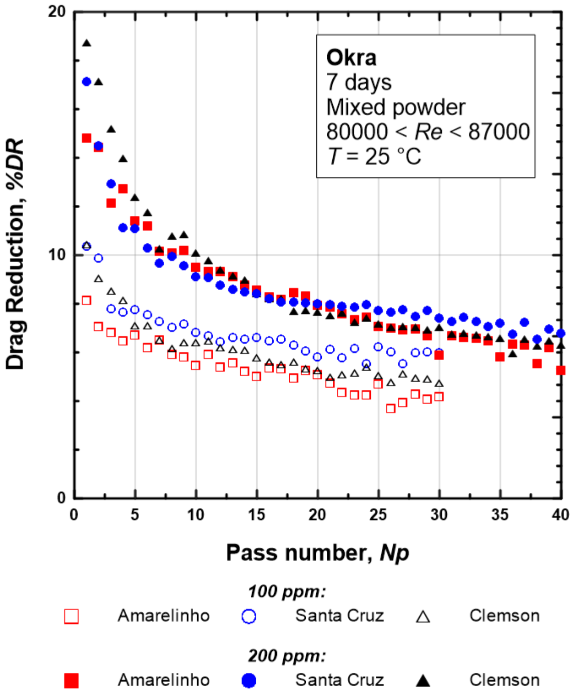


Figure 6. Effect of the concentration of each variety of okra on drag reduction.

As expected, the results depicted in Fig. 6 shows that the increase in concentration caused an increase in drag reduction, for the three varieties of okra. Moreover, for both concentrations, the maximum drag reduction (MDR), which corresponds to the first pass, was higher for the Santa Cruz okra, followed by Clemson and Amarelinho varieties. However, as the pass number increases, the value tends to an asymptote. According to Pereira e Soares (2012) it happens due to the desagregation of the polymer, because natural polymers are rigid and do not degrade mechanically. Therefore, after 20 passes, the difference becomes negligible, given the error intrinsic to the equipment, which means that for steady-state applications, there would be no loss of efficiency regardless of the type of fruit used.

Regarding the maturity index, only fruits of the Santa Cruz variety were analyzed for the concentration of 200 ppm, due to the limited amount of material. The harvest was chosen 7, 12 and 15 days after the flowers apparition. Fig. 7 represents the results of these tests.

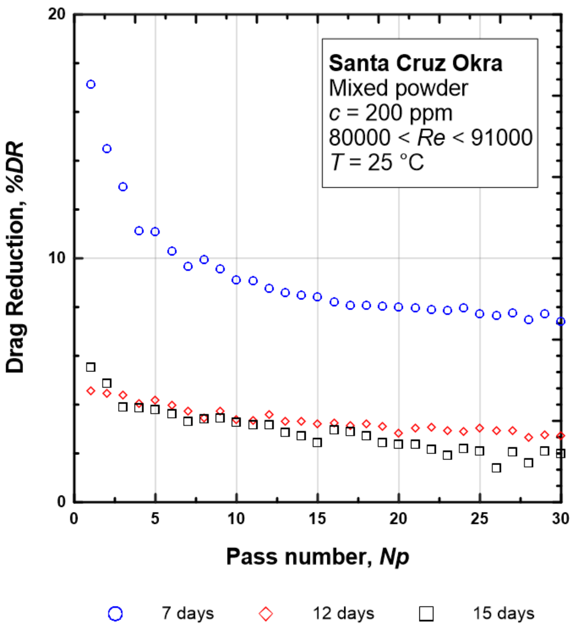


Figure 4. Effect of maturity index on efficiency of Santa Cruz okra variety as drag reducer.

As presented in Figure 7, the younger okra, harvested at 7 days, showed a drag reduction above the others, both in the first pass (MDR, 17% against 7%) and in the permanent regime (asymptotic value, 8% against 2%). Between the older samples, no significant differences were found. It was expected by the chemical spectra showed in Fig. 2(b) and discussed before, because the young okra apparently has more polymers in its composition. This result can also be related to Noorlaila *et al.* (2015) conclusions that the younger fruits can produce more mucilage than older and harder fruits. This indicates that the mucilage is a better drag reducing than the fibers.

In conclusion, the results show the influence of maturity index and variety of plant on biopolymers' efficiency as drag reducing agents. It was found that for steady-state applications, there's no notable difference between Amarelinho, Clemson or Santa Cruz varieties. On the other hand, for Sant Cruz okra variety, maturity index can affect the drag reduction significantly and the younger fruits are the most efficient among the three harvest ages evaluated.

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5. RESPONSIBILITY NOTICE