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Studies on Rheological Properties of 3D Printable Millet Based Dough

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ABSTRACT: 3D food printing is a new technology that has the potential of giving the appropriate individuals the correct nourishment. The primary technology behind 3D printing is additive manufacturing, in which layers of food are produced and then topped one above the other. To address India's malnutrition, millets are combined with 3D printing technology as they are nutri-cereals supplementing calcium, protein, niacin, and many other vital nutrients. This study analyses the printability of the millet-based dough by investigating their rheological characteristics. The interaction of dynamic viscoelastic characteristics with angular frequency, including storage modulus (G') and loss modulus (G") was measured. Strain rate of 0.05%, was chosen to set up linear viscoelastic range to perform the oscillation test. Regardless of the addition of xanthan gum, the values of G' and G" increased with increase in angular frequency for all millet-based dough. It demonstrates that the dough made of millet behaves as an elastically active gel-like structure that helps printed products to maintain their shape.

Keywords: 3D Food Printing, millet, shear thinning, additive manufacturing technology, hydrocolloids, dynamic viscoelastic properties, rheology.

INTRODUCTION

Native to India, millets are nutritious crops that are high in niacin, phosphorous, calcium and other vital nutrients. Despite being highly valued crops, after the green revolution, their percentage of cultivation fell from 40% to 20% (ICRISAT, 2017). Numerous minor millets are either extinct or rarely cultivated. Millets are becoming more significant today as people hunt for alternatives that are both nutritious and quick to eat. Therefore, it is imperative to create technologies that can quickly and conveniently make healthy food without compromising millet's nutritional value or endangering the consumer's health. In terms of malnutrition, India ranks 107th, meaning that almost 40% of children lack access to basic nutrients. Therefore, it's important to create a product that has all the elements required for a balanced diet. Most technologies or processing techniques either eliminate critical nutrients or demonstrate a decrease in their bioavailability. Therefore, it is crucial to create a method that improves the material's bioavailability. One such technology that fulfills our criteria is 3D food printing.

3D printing is based on additive manufacturing technology that gives a 3- dimensional structure to the product (Attaran, 2017). Designers have a great degree of leeway to experiment with unique geometric forms since complex items may be produced fast using 3D printing without being limited by design complexity (Jiang *et al.*, 2019). Food customization necessitates specialized hand-made skills and significant production costs. Cakes could be cut into a variety of forms for customization, but doing so would be inefficient as it produces many scraps which cannot be utilized further and are then considered waste, but 3D printing helps in reducing waste as it utilizes all the material (Prakash *et al.*, 2019). The molding process would take more than 24 hours to create a certain shape whereas 3D printers can print products in less time compared to conventional methods (Lipton *et al.*, 2015).

Rheological properties play an important role in accessing the printability of the product. In this study, two types of tests are performed, they are steady rotational test and dynamic oscillatory test. The dynamic oscillatory test helps us to understand the viscous or elastic behavior of the formulated composition (Huang *et al.*, 2020). A Steady rotational test is used to study the behavior of dough concerning apparent viscosity and shear rate.

Sakiyan *et al.* (2004) investigated the influence of fat and emulsifier in cake batter by studying its rheological properties. It is found that apparent viscosity decreases with the addition of fat and emulsifier and the batter exhibited shear thinning properties. Shinoj *et al.* (2006) reported the rheological properties of minor millet flours and found when the storage modulus shows a higher value than the loss modulus, then the paste formulated tends to behave like a weak gel. Viscosity and shear rate are determined by Schramm (1994). The viscosity of a substance, which influences printability, is a measure of its resistance to force. Shear stress is the force that causes distortion, while shear rate is the rate at which deformation occurs. To be strong and sustainable, a potential food material must have a shear rate, viscosity, and shear stress combination, according to Zeng *et al.* (2021).

So far, no studies have been made exclusively on the rheological properties of millet-based dough that depict the printability of the material. Therefore, this study focuses on the printable characteristics of millet-based dough by studying their rheological properties.

MATERIALS AND METHOD

Materials

Barnyard Millet flour was bought from a local grocery market in Coimbatore, Tamil Nadu, and xanthan gum, a food additive, was bought from the Urban Platter.

Optimisation of millet-based dough. To ensure that the flour's particle size is uniform, the purchased barnyard millet flour was initially sieved through a 0.2 mm sieve. Barnyard millet flour, refined wheat flour, rice flour, milk powder, sugar, egg, butter, and xanthan gum are the ingredients used in making this functional food. Initially, sugar and butter were mixed in a planetary mixer at 60 rpm for two to three minutes. Following that, a whole egg was added to the creamed mixture and properly combined. The other weighed components were then added and mixed for 2–3 minutes at 60 rpm in a planetary mixer.

Steady shear measurement. The rheological properties of millet-based dough were investigated using a parallel plate rheometer (MCR 52 series, Anton Paar Co. Ltd., Austria) The two parallel plates were separated by 1 mm distance for carrying out the test. The millet-based dough was kept at 25 °C for 60 minutes to allow for settling before the rheological test. Increasing the shear rate from 10 to 100 s^{-1} at 25 °C allowed researchers to determine the stable shear viscosity of millet-based dough. Following sample loading, the geometry was modified to fit the 1 mm gap measurement and a superfluous sample was removed from the edges. With the collected rheological parameters, the Ostwald model was fitted to explain the relationship between shear rate and apparent viscosity (Martínez-Cervera *et al.*, 2012).

Dynamic viscoelastic properties

Oscillatory frequency test. A rheometer (MCR 92 series, Anton Paar Co.Ltd., Austria) was used to measure the dynamic viscoelastic characteristics of the millet-based dough using a small amplitude oscillatory frequency sweep test. Initially, the samples' linear viscoelastic range (LVR) was calculated using strain sweeps (0.1 to 100 rad/sec) at a constant frequency of 1 Hz. The viscoelastic linear section was subjected to a frequency sweep test at 0.05 per cent strain with a frequency range of 0.1 to 100 rad/s at 25 °C. Using the program RheoCompassTM (Anton Paar, Graz, Austria), the dynamic rheological characteristics of the millet-based dough were captured. These characteristics included the shear storage modulus (G'), which describes the elastic behavior of the samples, and the shear loss modulus (G''), which explains the viscous behavior of the sample (Ronda *et al.*, 2011).

Temperature sweep test. Using a temperature-controlled rheometer (MCR 92 series, Anton Paar Co. Ltd. Austria), a temperature sweep test was performed at an angular frequency of 5 rad/s and a heating rate of 5 K/min. The temperature was varied from 25 °C to 180 °C. It was done to measure dynamic viscoelasticity (Bozdogan *et al.*, 2019). The storage modulus (G') and loss modulus (G'') was measured using the program Rheo CompassTM (Anton Paar, Graz, Austria).

RESULTS AND DISCUSSIONS

Steady shear properties. For the dough to be continuously extruded from the nozzle of the 3D printer, its flowability must be considered (Krishnaraj *et al.*, 2019). The non-Newtonian shear thinning characteristics of the dough are connected to flowability. Shear rate increases with a reduction in apparent viscosity for a dough that exhibits shear thinning behavior (Zhong *et al.*, 2013). Fig. 1 shows that the prepared dough with xanthan gum exhibits shear thinning characteristics, demonstrating that the material can be printed successfully. When viscosity and shear rate are fitted in the Ostwald model, the flow behavior index (n), consistency index (K), and regression coefficient (R^2) are obtained (Table 1).

Dynamic viscoelastic properties. Fig. 2 depicts the relationship between dynamic viscoelastic properties like storage modulus (G') and loss modulus (G'') concerning angular frequency. When angular frequency rises, both the storage modulus and the loss modulus exhibit an increase in value. This demonstrates that the developed formulation is elastically active and exhibits a gel-like structure, which is required to maintain the product's structure throughout and after printing (Huang *et al.*, 2019). Additionally, G' is greater than G'', indicating that the dough has an elastic, gel-like structure. High G' and G'' values point to a viscoelastic behavior that relates to the mechanical stability of the dough during printing. High readings also show xanthan gum's ability to bind with water (Singh *et al.*, 2016).

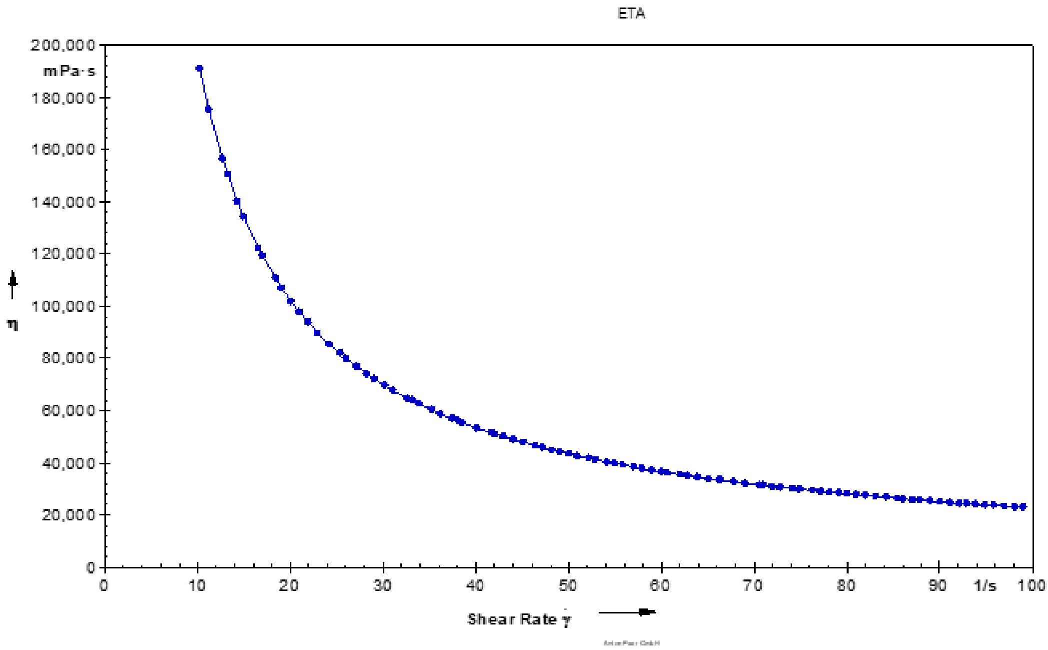

Fig. 1. Relationship between apparent viscosity and shear rate for millet-based dough.

Table 1: Values of Consistency Index (K), Flow behavior index (n) and Regression coefficient (R^2).

Sample	k	n	R^2
Millet based dough	1675.4	-0.93	0.949

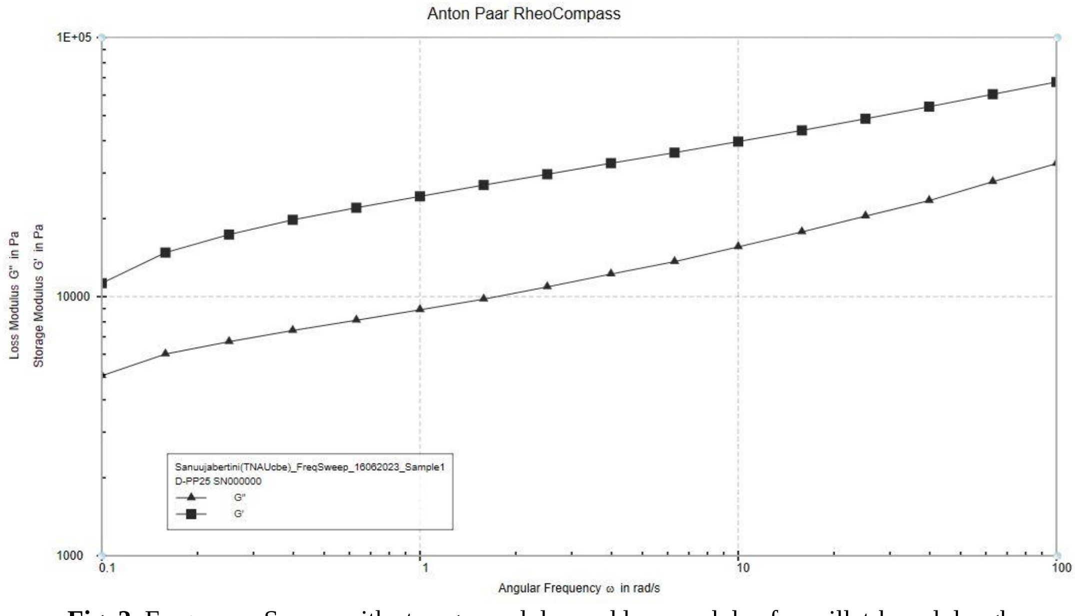

Fig. 2. Frequency Sweep with storage modulus and loss modulus for millet-based dough.

Temperature sweep test. Using a temperature sweep test, structural changes in the 3D-printed dough are examined during baking. Fig. 3 displays the changes in dynamic viscoelastic characteristics that were noticed at temperatures ranging from 20 °C to 180 °C. When energy is absorbed by the starch molecules or when the protein network expands, values of G' and G'' drops (Bozdogan *et al.*, 2019). This decrease in the values of G' and G'' is observed at a temperature of 90 °C in the millet-based dough. The values of G' and G'' are then seen to rise suddenly, followed by an abrupt decline. This drop in value represents the product's structural degradation during baking which occurs as a result of protein network denaturation (Rosell and Foegeding, 2007). Increased G' and G'' values aid in maintaining the shape of the 3D-printed product during post-processing. As the viscoelastic nature of the dough is increased by protein aggregation, the addition of xanthan gum enhances the value of G' and G'' and preserves the shape of the 3D printed throughout baking (Wüstenberg, 2014).

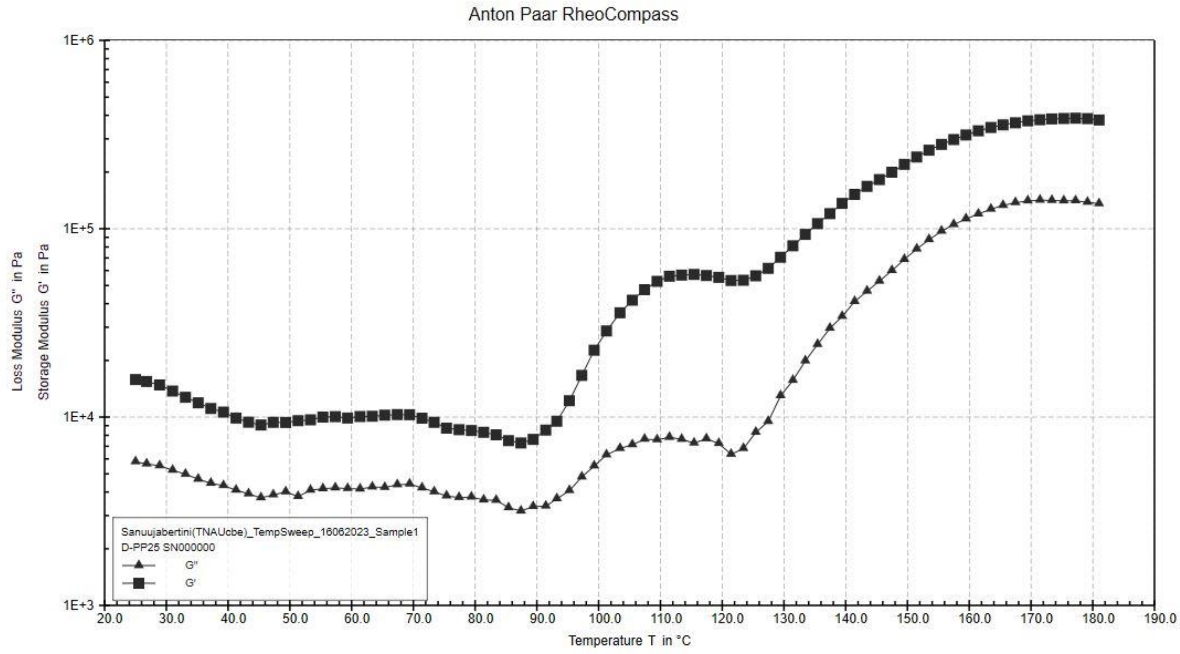

Fig. 3. Storage modulus (G') and Loss modulus (G'') against temperature curve during temperature sweep test.

CONCLUSION

In this research, the rheological properties of millet-based dough were studied. Small amounts of hydrocolloids can make a good difference in rheological behaviour. For a material to be printed effectively, it is evident from the research that the material should possess shear thinning behaviour. The viscoelastic behaviour of the dough is indicated by the high values of G' and G''. High values are also a result of the water-binding effect of xanthan gum. In conclusion, the rheological properties of any material to be printed are necessary to assess the mechanical stability and printability of that printed product.

FUTURE SCOPE

3D printing technology has a huge scope as it produces personalized food without much wastage. This technology can be employed in various sectors like baking and confectionery, meat industry and so on as it reduces manpower and provides high quality food.

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Conflict of Interest. None.

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