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# Rheological characterization of broken rice-barnyard millet-green gram flour blends

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## Abstract
Rheological characterization of the various flours from the broken rice, barnyard millet and green gram flour were investigated for flow behaviour, fluid model fitting, swelling power and solubility index. Results indicated out that each of the different flour might be utilized for specific applications in food processing. The flour combinations includes (broken rice, barnyard millet and green gram flour) - Mix 1- 80:10:10; Mix 2- 60:20:20; Mix 3- 40:30:30; Mix 4- 50:30:20; Mix 5- 50:20:30. The swelling power of invariably higher for mix 1 flour indicated the pastes were dependent on the swelled starch–protein complex granules and the formation of new cross-links in the network, and solubility were higher for mix 5. The flow behaviour of the prepared of different blend combinations showed that shear stress increased with increase in shear rate. It shows the behaviour of a non-Newtonian fluid, meaning that their viscosity is dependent on shear rate or the deformation caused on the sample. Model fitting was done with fluid models like casson, bingham, power law and Hershel bulkley models of all the best fitted models was Hershel bulkley giving $R^2$ values. Rheological data was fitted well for the Hershel bulkley model with $R^2$ value ranging from 0.90-0.99. Flow index (n-value) for the combinations observed from the table was less than 1 (n<1), which indicated the shear thinning behaviour of the formulations. Consistency index was in the range of 0.2- 1.5 and confirms viscous nature of the fluid.

**Keywords:** Flow behaviour, fluid model fitting, swelling power and solubility index

## Introduction
Barnyard millet comes under the category of Minor millets they are popularly known as coarse cereals and included in the broad category of cereals. Minor millets are nutritionally superior to rice and wheat and the presence of all the required nutrients in millets makes them suitable for industrial scale utilisation in the manufacture of food stuffs (e.g. baby foods, snack foods and dietary food). During processing such flours undergo the process of gelatinisation.

Rice (*Oryza sativa*) is one of the major cereal crops worldwide and it is consumed principally as a grain obtained from specific varieties. The understanding of their rheological behavior is very important for optimizing industrial applications and allowing consumer to select appropriate types for different culinary recipes (Correa *et al.,* 2013) [2]. In the food industry, starch based products like cereal flours are cooked during extrusion processes. Green gram being rich in quality protein, minerals and vitamins, they are inseparable ingredients in the diets of a vast majority of Indian population. When supplemented with cereals, they provide a perfect mix of essential amino acid with high biological value (Qin *et al.*, 2011) [6]

Therefore, the knowledge of their viscous behaviour is required to process them because the choice of the optimal processing conditions and the quality of end products depends on the rheological properties of the material (Lawal *et al.*, 2008) [4]. Processes such as baking of bread and cakes, extrusion of cereal-based products, thickening and gelling of sauces and pie fillings are all dependent on proper starch gelatinisation. In many instances, the food industries have to handle cooked suspensions of cereal flours such as gravy, soup, heat set gel, porridge, instant powders and modified flour and starches for speciality foods (Abdel *et al.*, 2008) [1]

This study was to investigate the use of formulation combinations and to provide basic information for the further application of broken rice, barnyard Millet and green gram in food extrusion industry.

## Materials and Methods
### Raw materials:
Broken rice, Barnyard millet and green gram were cleaned to remove dirt and discoloured grains, washed with water and sun dried by placing on clean cloth. The sample was made into flour using a burr mill in a local flourmill to a 100-micron particle size that passed through ISS 40 metal sieve and cooled to room temperature to avoid clump formation and stored in airtight

containers for further experiments. Calculated amount of flour and distilled water were taken to obtain the fresh paste. The slurry was prepared in the ratio of 5g of flour and 25ml of distilled water (Musa *et al.*, 2010).

**Table 1:** Flour composition

| Blend | Broken Rice % | Millet % | Green gram % | Total % |
|---|---|---|---|---|
| Mix 1 | 80 | 10 | 10 | 100 |
| Mix 2 | 60 | 20 | 20 | 100 |
| Mix 3 | 40 | 30 | 30 | 100 |
| Mix 4 | 50 | 30 | 20 | 100 |
| Mix 5 | 50 | 20 | 30 | 100 |

## Dynamic measurements

### Flow behaviour

The study was conducted at a controlled shear rate (CSR) mode for broken rice, Barnyard Millet and green gram flour samples at three different temperature 90 °C. Measurement were made using an upper movable parallel plate (PP 50) rheometery setup attached to measuring head and lower fixed base platform held along P-PTD 200/AIR has an integrated air heat exchanger. The freshly prepared paste was placed between the plates and experiment was carried out. The shear rate was increased from 0.01 to 100 s-1 at varying shear stress at shearing with 25 measuring point were generated and each measurement were replicated (Wu *et al.*, 2010) [8]. The rheogram obtained from shear stress and shear rate values obtained were fitted four different rheological models that have software (Anton paar, MCR 52) though non linear regression analysis.

### Herschel bulkley model

$$\tau = \tau_0 + k\gamma^n$$

$\tau$ - shear stress(Pa)
$\tau_0$- yield stress
k -consistency coefficient
$\gamma$- shear rate($s^{-1}$)
n- flow behaviour index

### Swelling power and solubility index

The flour samples of (Broken rice, Barnyard millet and green gram) at 1 % w/v (dry basis) were prepared in a centrifuge tubes with closed screw caps and heated in a water bath for 30 min at 80 °C with minimum shear condition. After heating, the centrifuge tubes were immediately immersed in an ice bath to quickly cool the dispersion to room temperature. After cooling in ice for 5 min, samples were centrifuged at 4500 rpm at 5 °C for 15 min and then the supernatant was removed for the measurement of solubilized starch. The supernatant was dried to constant weight in a hot air oven at 105 °C. Precipitated paste and dried supernatant were weighed. All measurements were done in triplicate. The swelling power (SP) and solubility index (SOL) were calculated as follows (Abdel- Rahman *et al.*, 2008) [1].

$$\text{Swelling power (g/g)} = \frac{\text{Weight of sedimented starch (g)}}{\text{Weight of sample (g) (100- \% Soluble (d.b.))}}$$

$$\text{Soluble Index (\% d.b.)} = \frac{\text{Residue Weight (g) x water weight (g)}}{\text{Aliquot volume (ml) x sample weight (g)}} \text{x 100}$$

## Results and Discussion

The flow behaviour of the prepared of different blend combinations are presented in table 1. it is shown in the figure 1 that shear stress increased with increase in shear rate. It shows the behaviour of a non-Newtonian fluid, meaning that their viscosity is dependent on shaer rate or the deformation caused on the sample. As non-Newtonian fluid display a non linera relation between shear stress and shear rate having a yield stress. The shear stress value were seem to be higher for the four combination of Mix 4 (50:30:20), presence of yield stress value indicated the non-newtonion behaviour of the fluid.

It was observed from the figure 2. That for all the flour combinations the viscosity reached to a maximum in the initial shear rate and gradually decreased with increase in shear rate and this type of fluid behaviour is called shear thinning. The viscosity was found to be maximum for the flour Mix 3 (40:30:30). On lowering the broken rice content, the viscosity increased in the combinations. Shear thinning behaviour might be due to the structural break down due to the hydrodynamic force or rate of particle disassociation might be higher than the rate of association under applied hydrodynamic force. The degree of shearthinning depends on the structural state of the dispersion prior to shearing and on the composition of the dispersing phase.

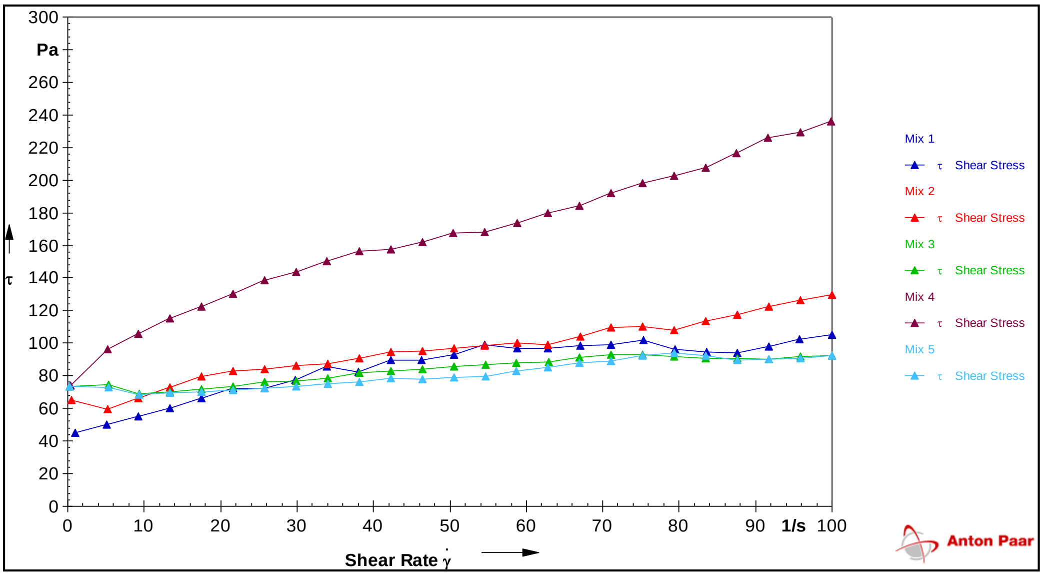

**Fig 1:** Effect on viscosity on varying shear rate for blends

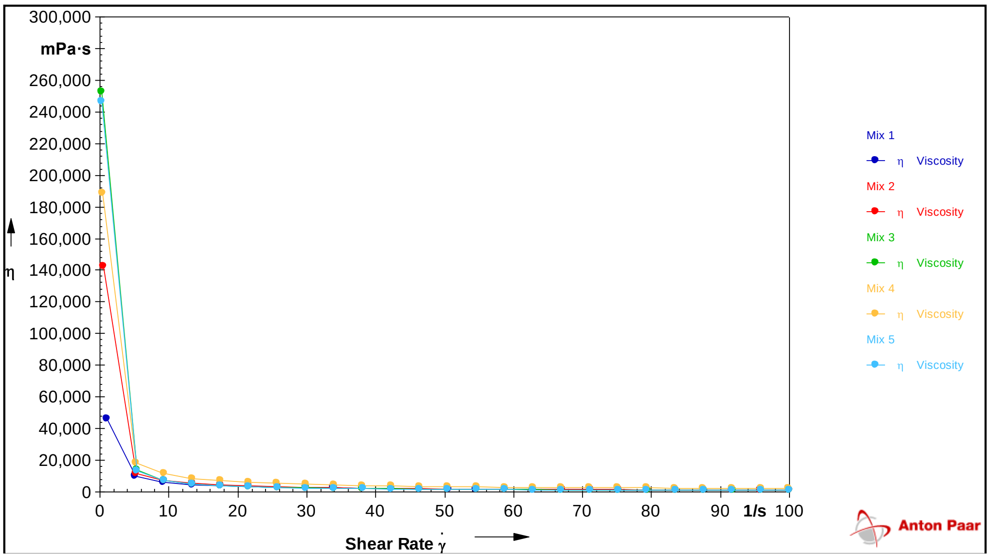

**Fig 2:** Flow curve for the blend

## Modelling of Rheological Behavior

Model fitting was tried with fluid models like casson, bingham, power law model and Hershel bulkley model of all the best fitted models was Hershel bulkley. Parameters obtained after fitting in to the Herschel bulkley model is represented in the table 1. Rheological data was fitted well for the given model with $R^2$ value ranging from 0.90-0.99. Flow index (n-value) for the combinations observed from the table was less than 1 (n<1), which indicated the shear thinning behaviour of the formulations. Consistency index was in the range of 0.2- 1.5 and confirms viscous nature of the fluid

**Table 2:** Herschel Bulkley model fitted for the blends

| Blend | K (Consistency index) | n (Flow index) | $R^2$ |
|---|---|---|---|
| Mix 1 | 0.2 | 0.01 | 0.90 |
| Mix 2 | 0.3 | 0.10 | 0.97 |
| Mix 3 | 0.3 | 0.03 | 0.95 |
| Mix 4 | 1.5 | 0.96 | 0.99 |
| Mix 5 | 0.7 | 0.81 | 0.93 |

## Swelling power and solubility index

The swelling power (SP) and solubility index (SOL) of Broken rice, Barnyard millet and green gram flour are shown in Figs. 4 and 5, respectively. The ability of broken rice flour to swell in the presence of excess water was different from millet and green gram flours. The mix 1 (80:10:10) showed the highest swelling power and solunility index was maximu for mix 5 (50:20:30) compared to other combinations. Swelling was regulated by the degree of crystalinity of the starch granules and the swelling power was determined by the ability of starch granules to swell in the presence of excess water when heated. Swelling power of starches reflects the interactions between water molecules and starch chains in amorphous and crystalline domains, respectively (Kim *et al.*, 2012) [3]. The process of pasting can be expressed as the state that is largely associated with gelatinization of starch and retro gradation to a minor extent. The apparent viscosity of starch dispersions in water is strongly influenced by the extent of swelling of starch granules. Starch granules swell radially in the beginning of heat induced pasting, and when the temperature is increased, the amylopectin-rich granules swell tangentially (Shinoj *et al.*, 2006) [7]. As a consequence, the granules get deformed and lose their original shape. The presence of amylose in the continuous phase surrounding the swollen granules results in the formation of a gel on cooling. This result demonstrated that broken rice flour inhibited starch swelling and prevented amylose leach out than millet flour and green gram flour seemed to have no effect on these properties.

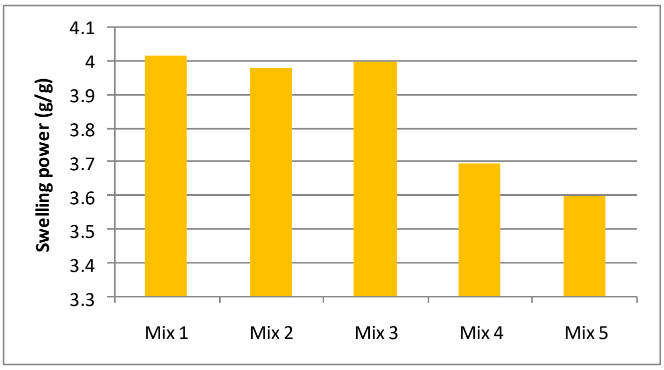

**Fig 3:** Swelling power of broken rice, barnyard millet and green gram

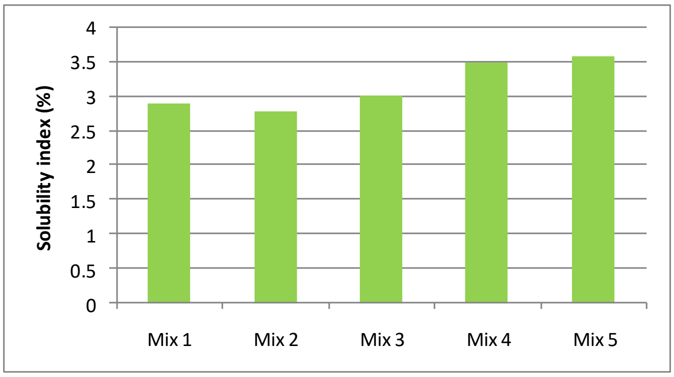

**Fig 4:** Solubility index of broken rice, barnyard millet and green gram

## Conclusion

The study showed flour formulations were significantly influenced on viscosity of the samples. Higher amount of millet and green gram led to higher consistency index values. All the combinations have shown shear thinning behaviour and followed the Herschel-Bulkley fluid behaviour with flow index value less than 1(n<1). On increased broken rice content the swelling power increased whereas solubility decreased.

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