Elucidating the Effect of Amylose on On-line Rheology of Pearl millet Flours during Extrusion

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Pearl millet extrusion

- Micro-nutrient rich
- ensures food and economic security amongst these malnutrition prone areas

- **Extrusion**: a useful tool to enable processing the otherwise unappealing millets into crunchy and nutritious snack foods.

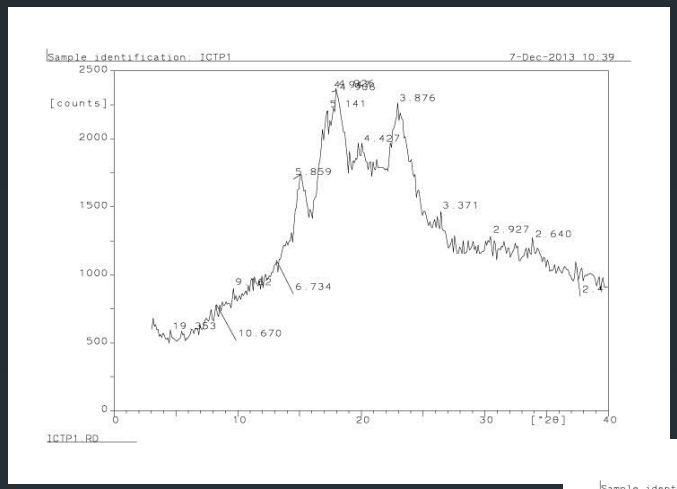
Amylose

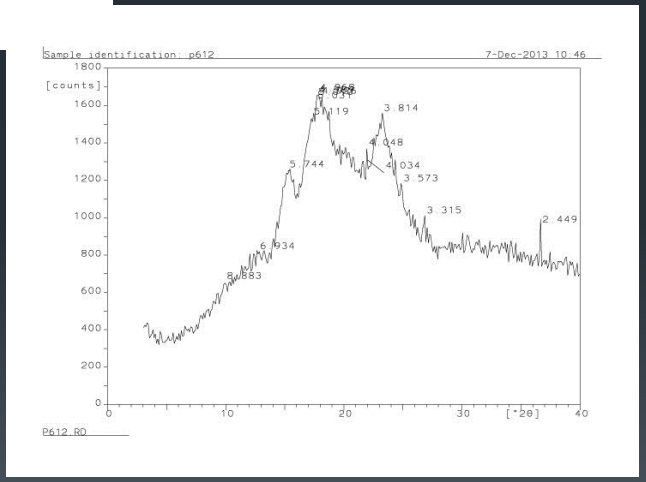
- Effect on the physical and functional properties of their extruded products is well documented
- Different viscosity models based on the traditional Power law function have been proposed to describe the rheological properties of dough.
- The melt rheology of starch-based materials is of both scientific and industrial importance, and thus it has been widely investigated especially in corn and wheat

Gaps

- No literature exists on the rheological behaviour during extrusion processing of millets flours varying in amylose contents
- Scant literature is available on the on-line rheological profile for whole grain flour
- Thus, the rheological behaviour of pearl millet flours upon varying their inherent amylose content, moisture percentage and barrel temperature was investigated

X ray diffractograms



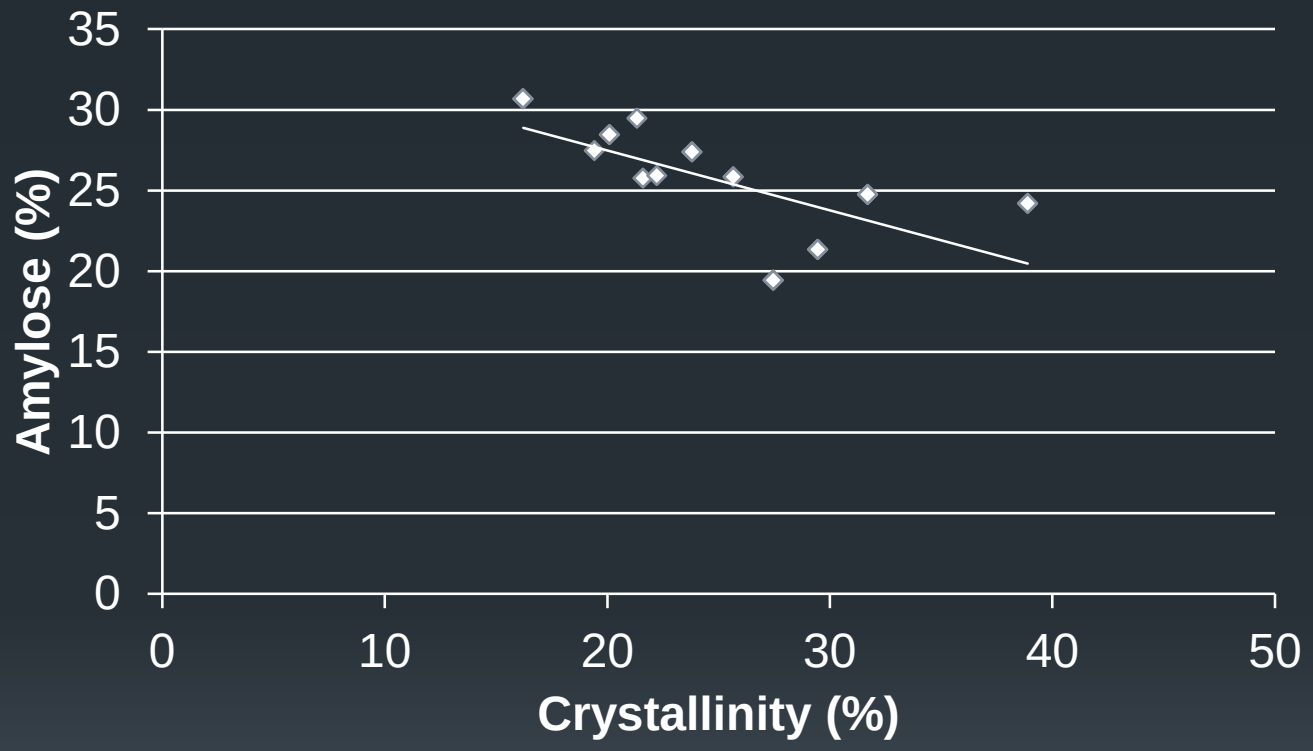


Cultivars	% Crystallinity
ICTP 8203	27.40
L 74	24.42
P 443	26.24
P 612	31.71

(a_w =0.44)

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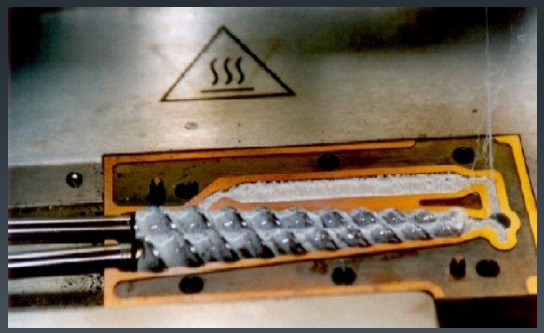
Amylose and Crystallinity



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On-line extrusion Rheology

- Barrel temperatures 70-90^{o}C
- Moisture content 23-28% (w.b.)
- Shear stress and apparent viscosity determined at varying shear rates (Using Haake twin-screw extruder; Minilab micro-compounder)



ΔL = 64mm; depth of the flow channel, *h* = 1.5mm, width of the flow channel, *w* = 10mm

Rheometry

- From the capillary geometry and the pressure drop, the shear stress "τ" at screw speeds varying from 30-180 min^{-1} were recorded for each rpm.

Viscosity

$$\eta = \frac{\tau}{\dot{\gamma}} = \left(\frac{\omega \times h^2}{12 \times \Delta L}\right) \times \frac{\Delta P}{\dot{V}} = C_v \times \frac{\Delta P}{\dot{V}} \quad ; C_v: 4.394 \times 10^{11}$$

Shear stress

$$\tau = \left(\frac{h}{2\Delta L}\right) \times \Delta P = C_1 \times \Delta P \quad ; C_1: 0.0117$$

Power law

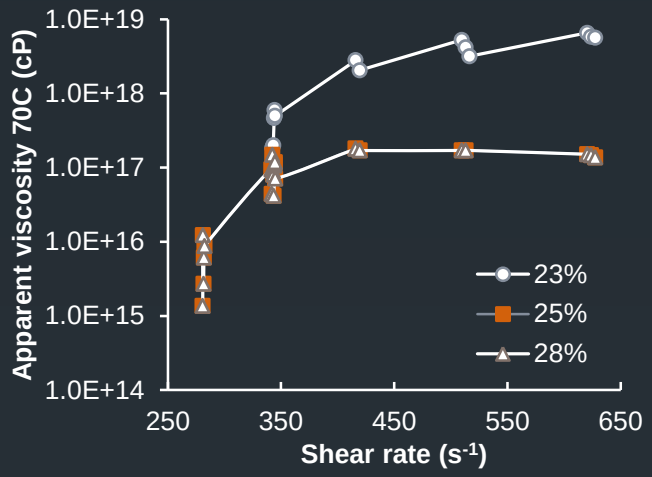
$$\tau = K \times \dot{\gamma}^n$$

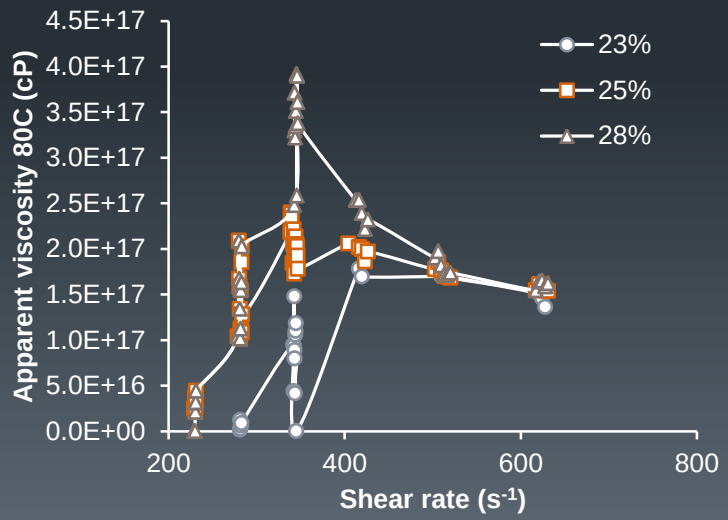
Steady shear viscosity

Effect of moisture

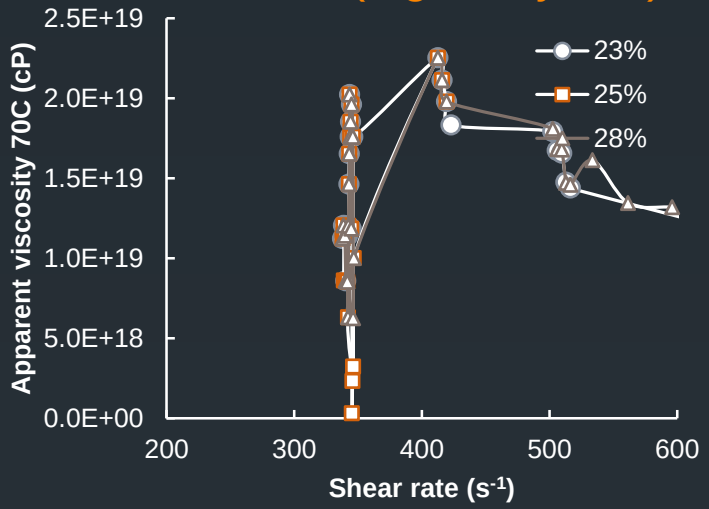
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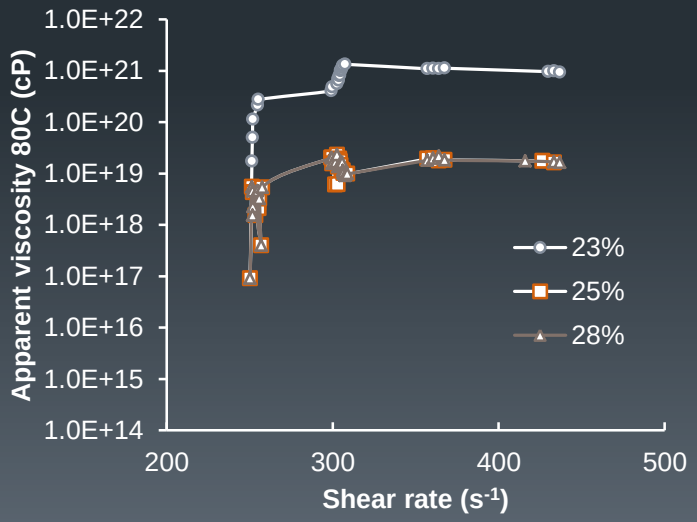
L 74 (low amylose)





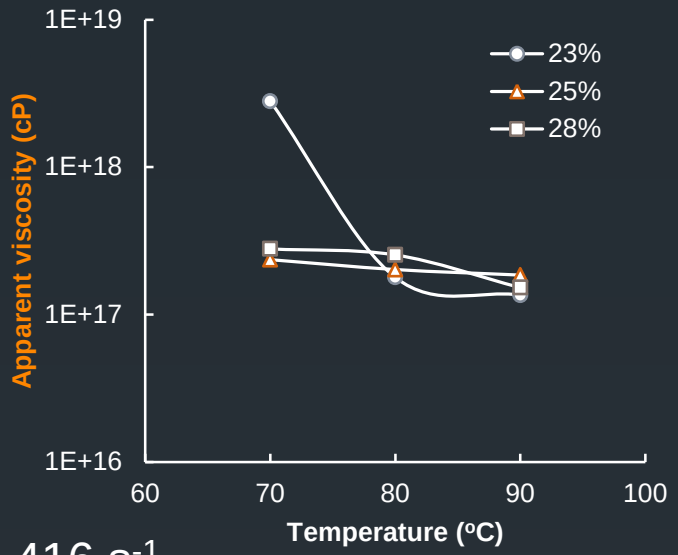
P 443 (high amylose)





Effect of barrel temp and moisture

L 74

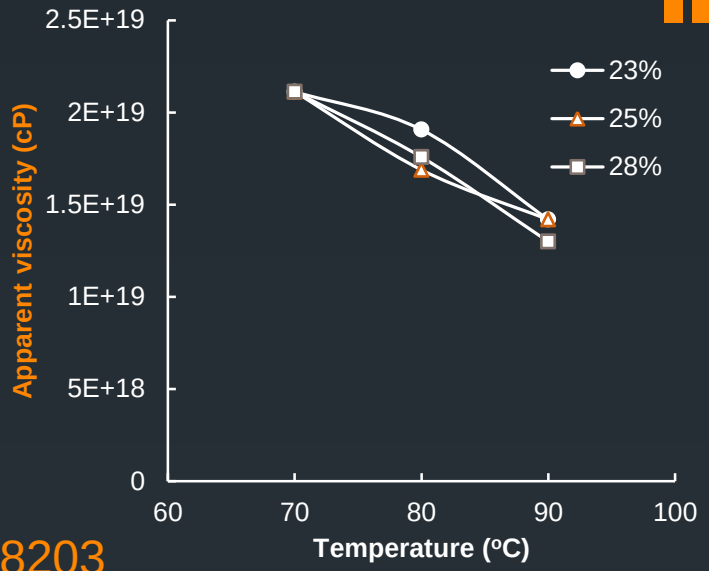


η: 416 s^{-1}

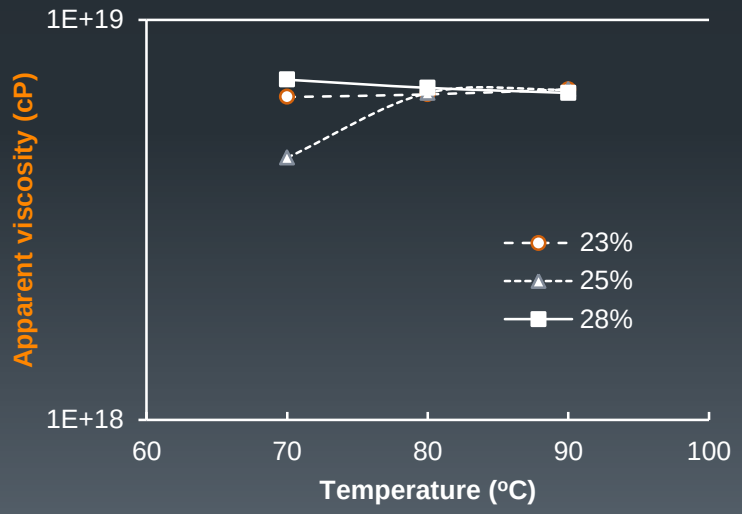
viscosity dec. with inc. in temperature

Structural transformations: Loss of starch crystalline structure, Destruction of granular structure, Rupture of glycosidic bonds and New molecular interactions

P 443



ICTP 8203



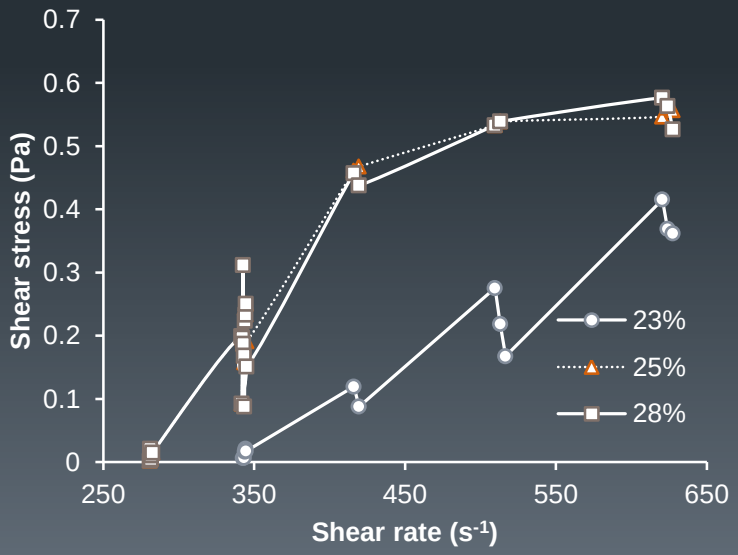
Moisture; Amylose and App Viscosity

- Effect of moisture incorporation is not much evident in case of higher amylose containing flours of P 443 and ICTP 8203
- Apparent viscosity is more sensitive to moisture content (Valle et al., 1996)
- Macromolecular degradation at lower amylose contents
- Higher glass transition temperatures of higher amylose flours might also be responsible for lesser effect of moisture increment upon their melt properties (Liu et al., 2010)

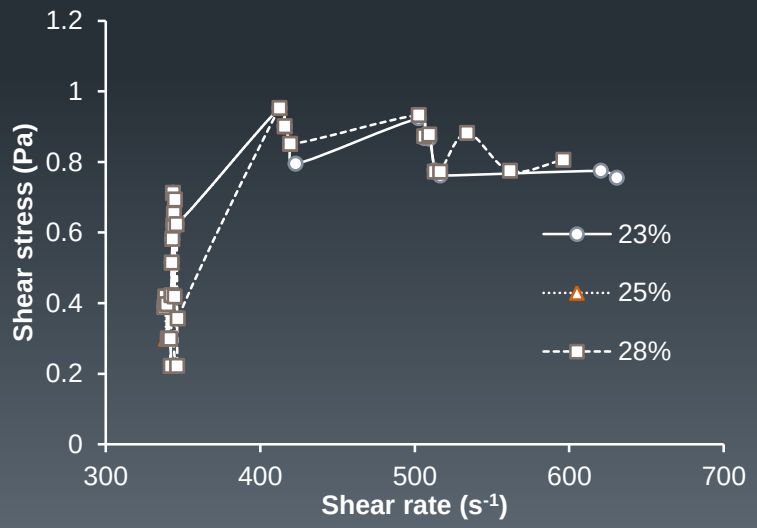
Shear stress

- L 74 : 0.002 to 0.57 Pa ; P 443: upto 0.95 Pa.
- Structure of starch having lower amylose content is easily disrupted by heating
- Amylopectin displays lower flexibility during thermo-mechanical transformations

L 74



P 443



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Power law

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Non-linear regression

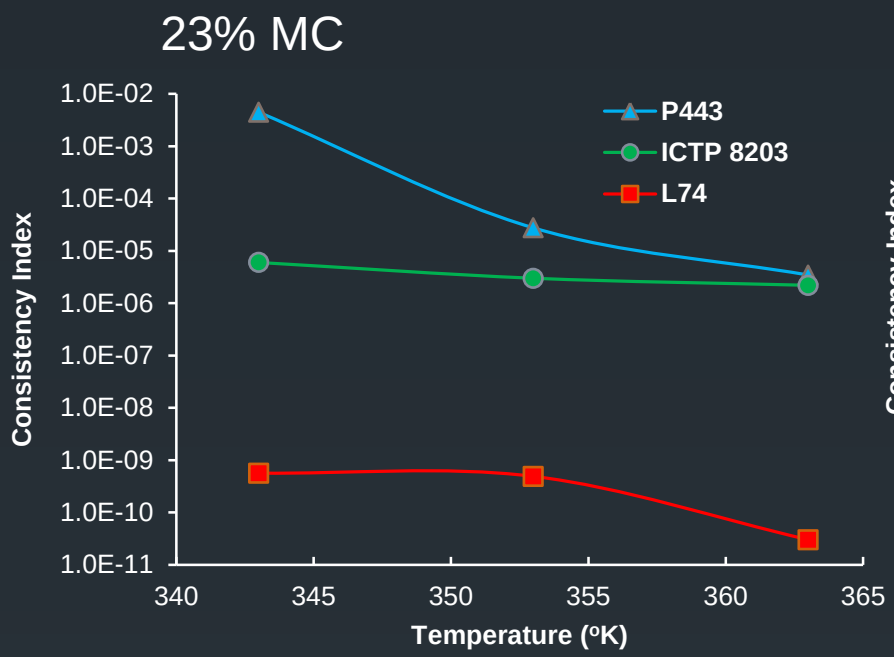
High values of R^2 and variance explained

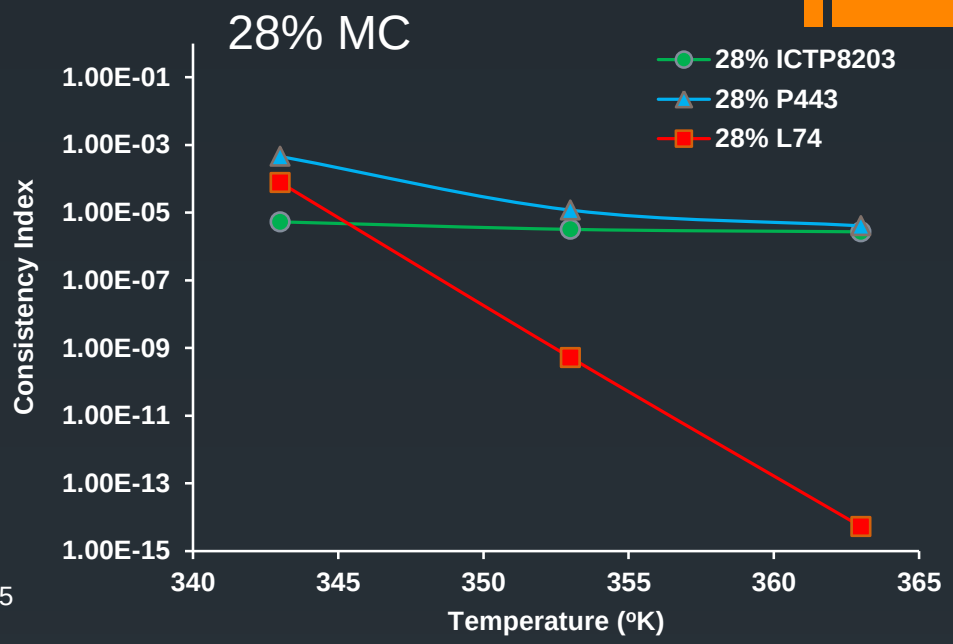
The consistency index of millet flours decreased with increasing moisture content (23 to 28%, wb) and barrel temperature (70-90^oC).

Flow behaviour index ‘n’ values> 1 (shear thickening)

Cultivar	MC	Activation energy (kJ/mol)	K_o	R^2	VE
P 443	23	105.56	3.3E-19	0.9059	82.08
P 443	28	95.68	1.02E-18	0.8832	78.01
L 74	28	91.23	8.19E-19	1.0	100.00

Consistency Index





& **Consistency indices ४ Amylose**

P H T **Activation energy of flow also increased with increase in amylose content of the millets flour.**

Activation energy Ea

Cultivar	MC	Activation energy (kJ/mol)	K_o	R^2	VE
P 443	23	-105.56	3.3E-19	0.9059	82.08
P 443	28	-95.68	1.02E-18	0.8832	78.005
L 74	28	-91.23	8.19E-19	1.0	100.00

Higher activation energy implies that a smaller temperature change is required to decrease the viscosity more rapidly.

Lower increase in temperature is required to decrease consistency index of low amylose flours having higher amylopectin.

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Discussion

- This can be explained by the microstructure and phase transition of starch during gelatinization, in which the double helical, crystalline structure formed by the short branched chains in amylopectin are torn apart.
- In amylopectin-rich starch there is lesser formation of gel-balls and super-globes after gelatinization,
- the entanglement of polymer chains is much less than that in amylose-rich linear starch.
- Thus lower amylose flours initially have lower modulus and higher elongation, and lower viscosity during extrusion.

Thank you

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