Theme 1

Biodegradable PVA/starch/bentonite polymeric blend to improve fertilizer use efficiency

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SOILS: WHERE FOOD BEGINS

Background

- Fertilizers ensure food security as evidenced from the phenomenal many-fold increase in food grains production and fertilizer consumption.
- Nitrogen (N) and phosphatic (P) fertilizers account maximum sharing in global fertilizer market (FAI, 2019).
- Achievable recovery efficiency is hardly 35–40 % for N and 15–20 % for applied P fertilizers.
- Flashed release of nutrient caused economic losses, nutrient loss and subsequent environmental pollution.
- The slow release fertilizer is defined as the fertilizer which releases the nutrient at slower rate for a longer duration aiming to synchronize plant demand (Shaviv, 2005).
- Most common and effective practice to manufacture SRF is encapsulation of granular fertilizers. However, degradability of encapsulating materials is major cause of concern.

Why PVA/starch/bentonite polymeric blend?

- Starch is a natural biodegradable macromolecule that composed of linear amylose and branched amylopectin.
- Indeed, poor structural qualities (brittle nature of starch films and high water-vapor permeability) of starch-based crosslinked polymers hinder its widespread uses (Ali et al., 2011; Ray et al., 2009).
- The combination of starch and biodegradable polymer like poly(vinyl alcohol) (PVA) increase film forming properties of starch after polymerization (Han et al., 2009; Priya et al., 2014).
- However, multiple numbers of surface-hydroxyl groups (–OH), excess hydrophilicity, high surface activity and inferior mechanical properties of starch/PVA films demands fillers for better mechanical strength (Tian et al., 2017).
- Notably, natural availability of bentonite in the lithosphere and cost-effective processing for clay-fractioned bentonite made it economically feasible than the other used filler materials (Hosseini et al., 2018).

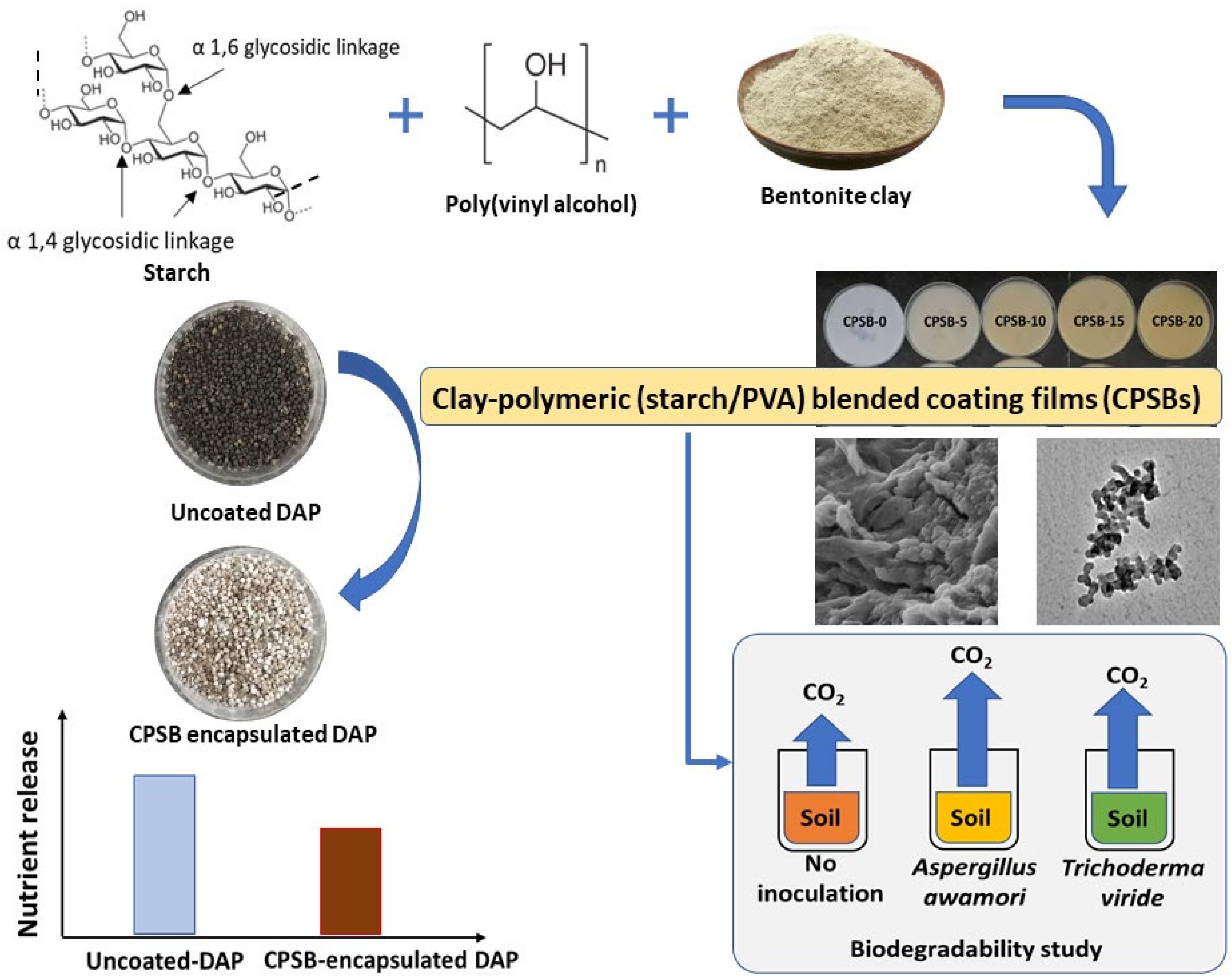
Methods

PVA : wheat starch (3: 7)

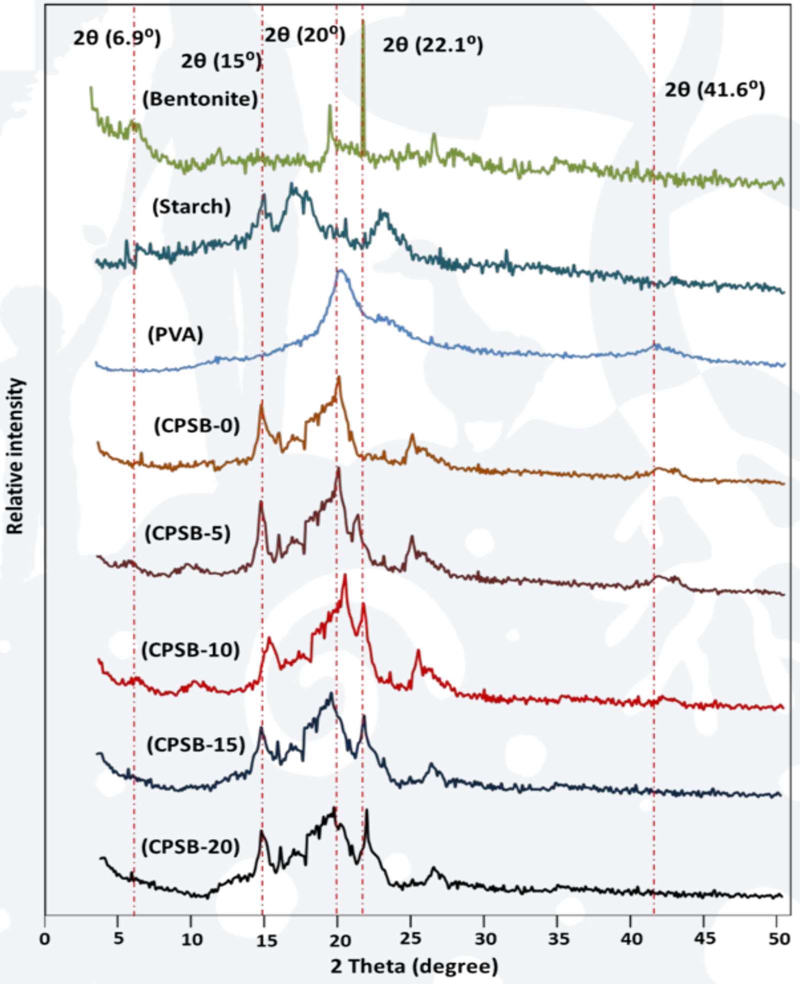
Added bentonite: 0, 5, 10, 15 and 20% (w/w)

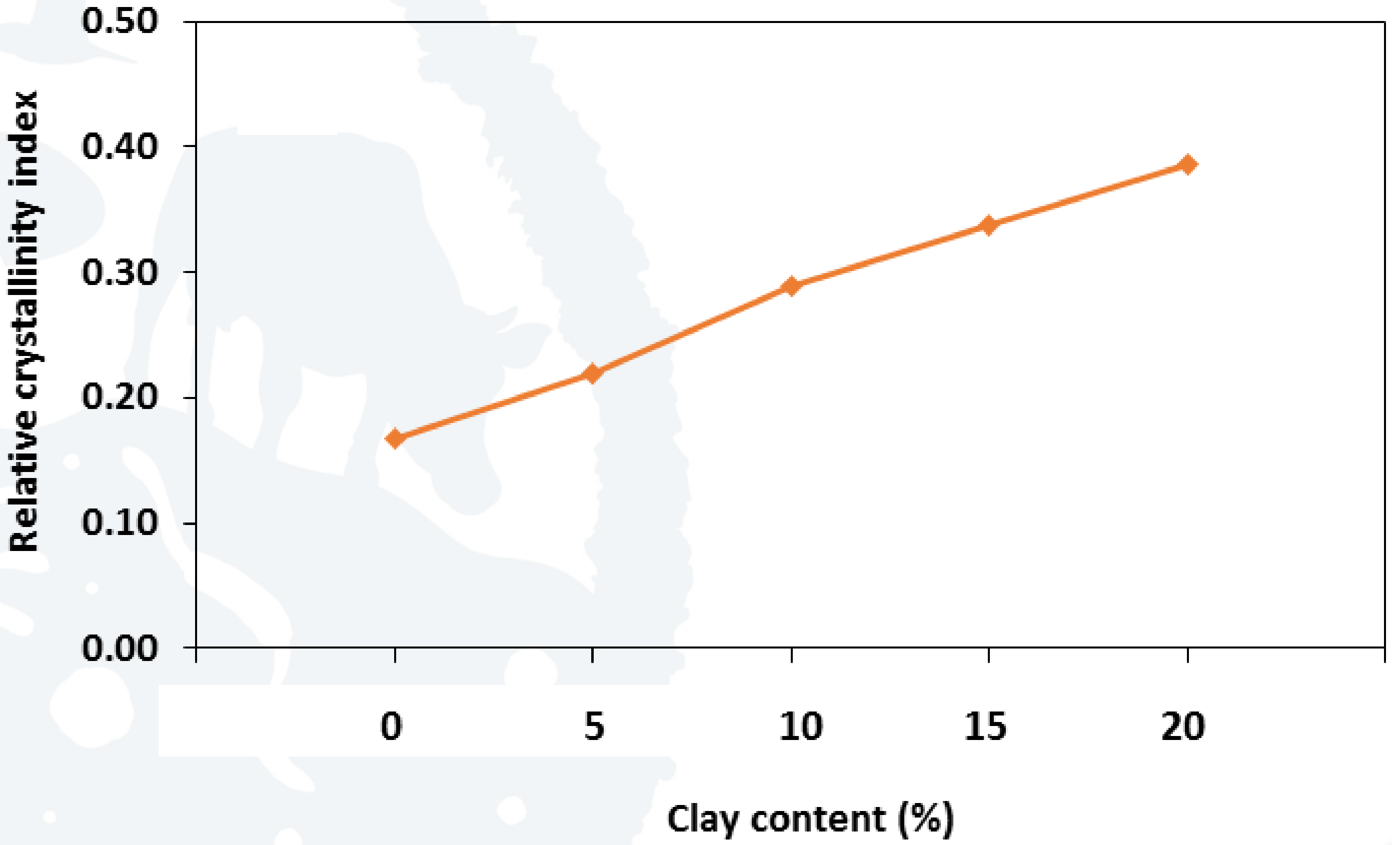
0.25M APS: 6.25 mL

Butanol: 0.5 mL



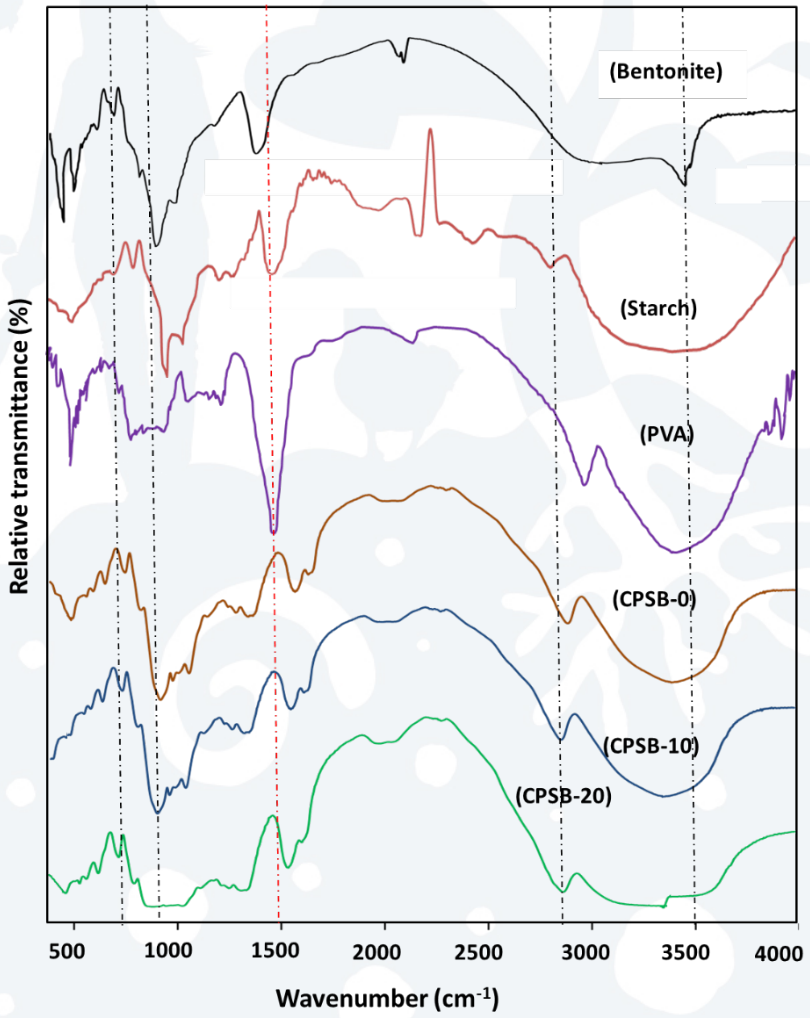
X-ray diffraction (XRD) pattern and crystallinity index of PVA/starch/bentonite polymeric blend

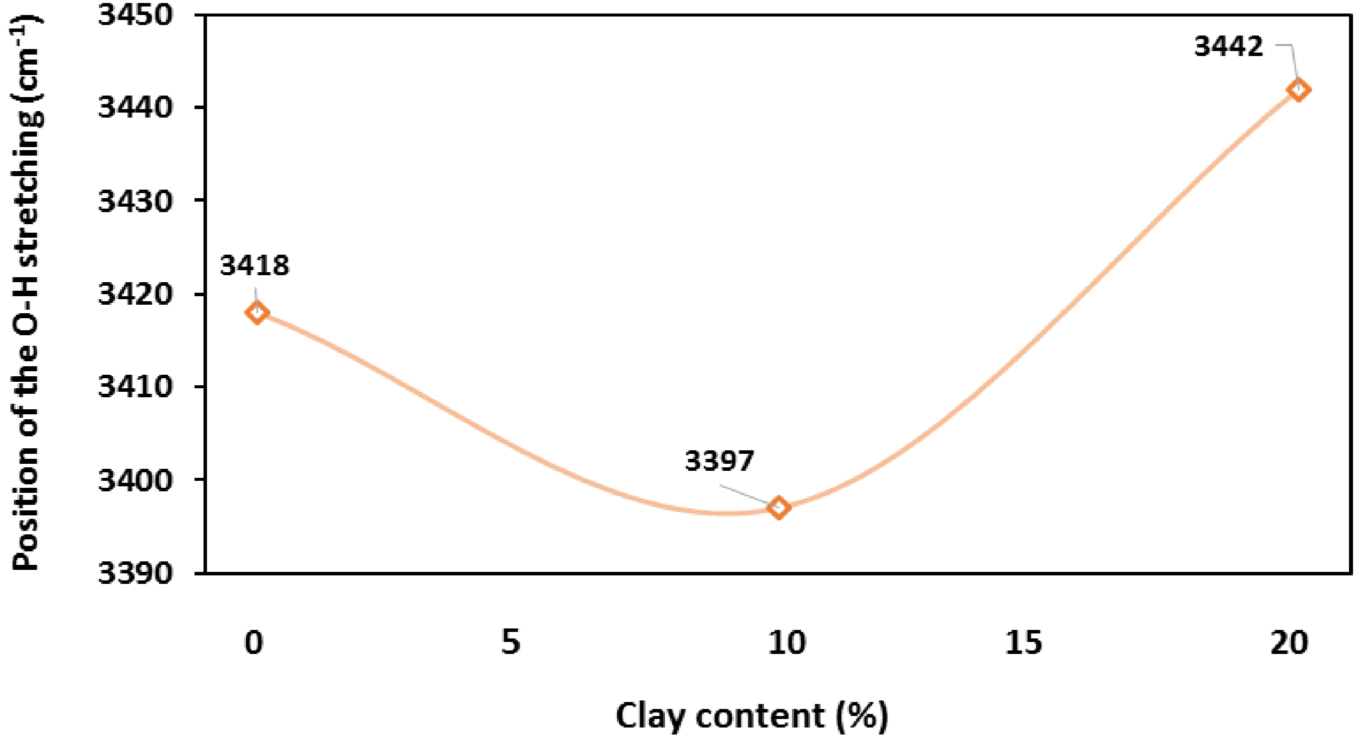




GLOBAL SOIL PARTNERSHIP

FTIR spectra and peak position for the O-H stretching of PVA/starch/bentonite polymeric blend

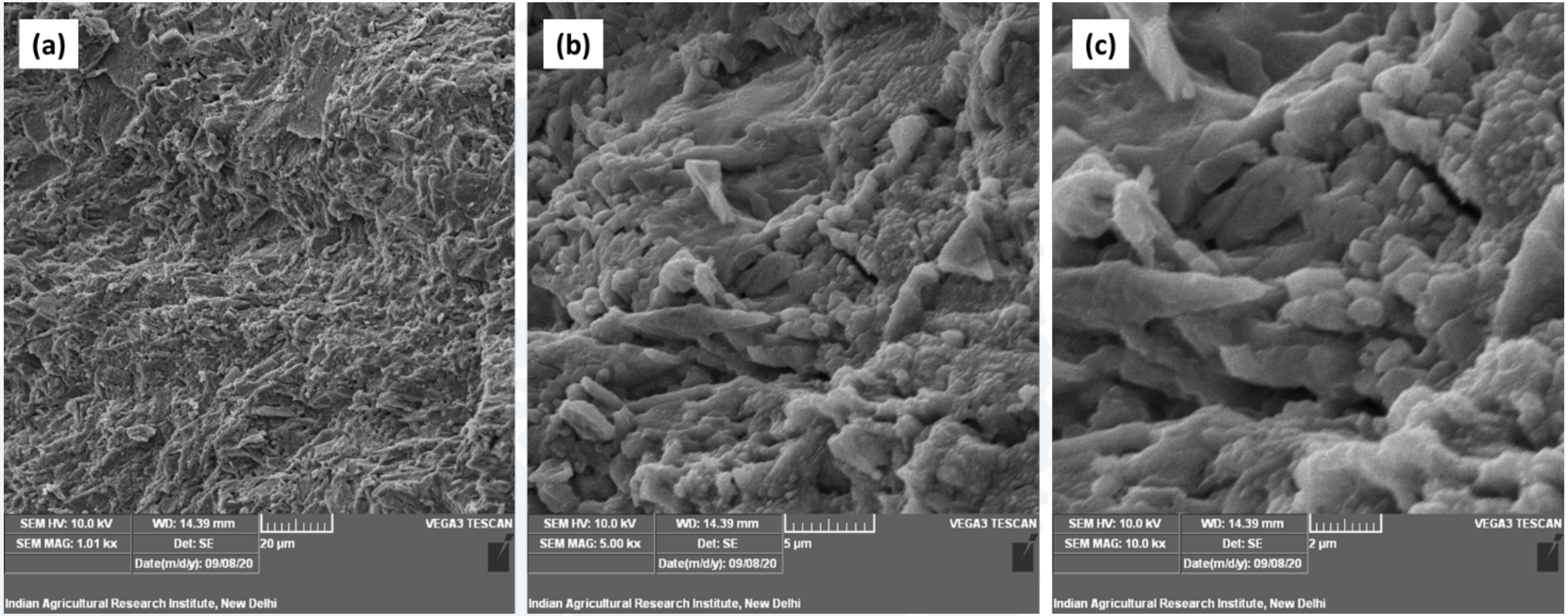




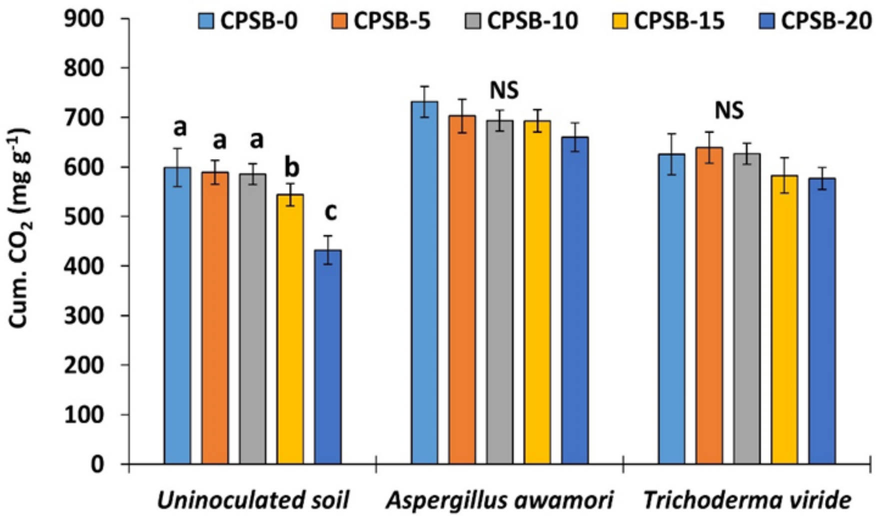
Structural parameters of different PVA/starch/bentonite polymeric blend

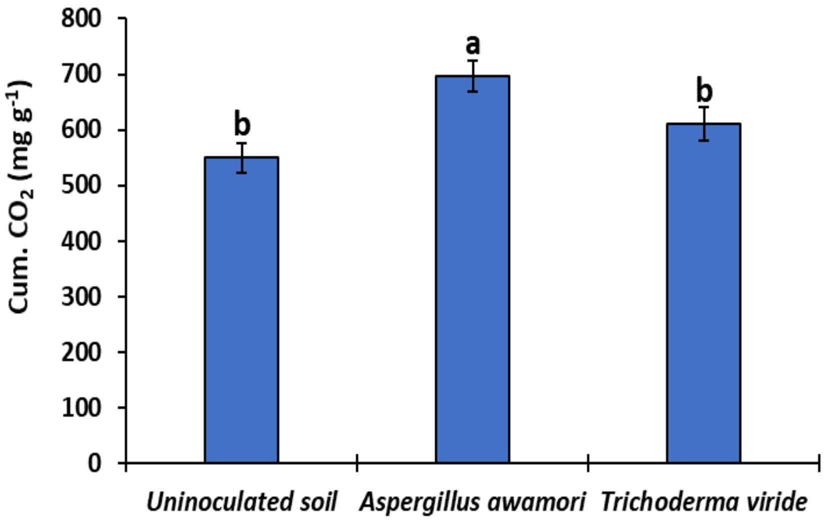
CPSBs	Density (Mg m^{-3})	Porosity (%)	Absorbency (%)	
			Deionized water	0.9% NaCl
CPSB-0	1.049 ± 0.002a	90.3 ± 2.37a	297.4 ± 7.05a	191.5 ± 2.73a
CPSB-5	1.058 ± 0.003d	88.0 ± 1.79ab	252.2 ± 4.22b	183.2 ± 3.44b
CPSB-10	1.073 ± 0.004c	86.4 ± 1.95bc	233.9 ± 8.62c	173.8 ± 5.56c
CPSB-15	1.084 ± 0.008b	85.2 ± 1.16c	209.3 ± 2.78d	140.4 ± 1.64d
CPSB-20	1.090 ± 0.008a	82.5 ± 1.28d	196.1 ± 3.27e	116.1 ± 5.98e

Scanning electron micrograph of CPSB-10 at (a) 1000 X, (b) 5000 X and (c) 10000 X magnification



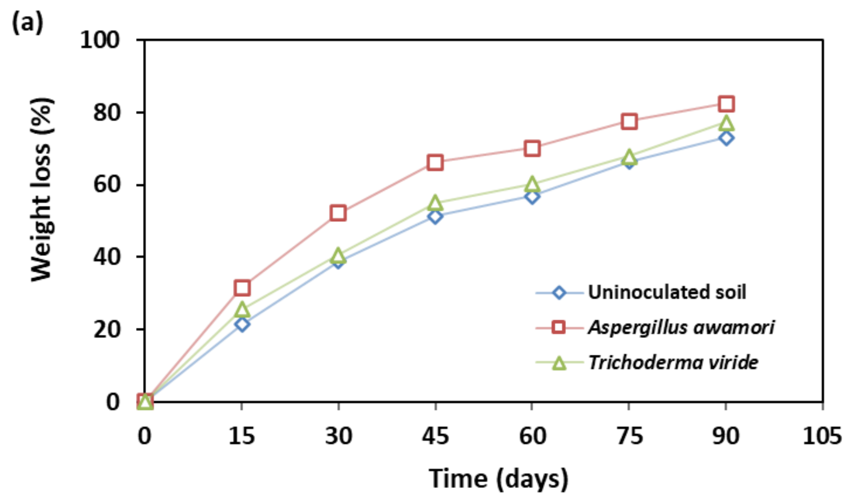
Biodegradation and half-life of different PVA/starch/bentonite polymeric blend

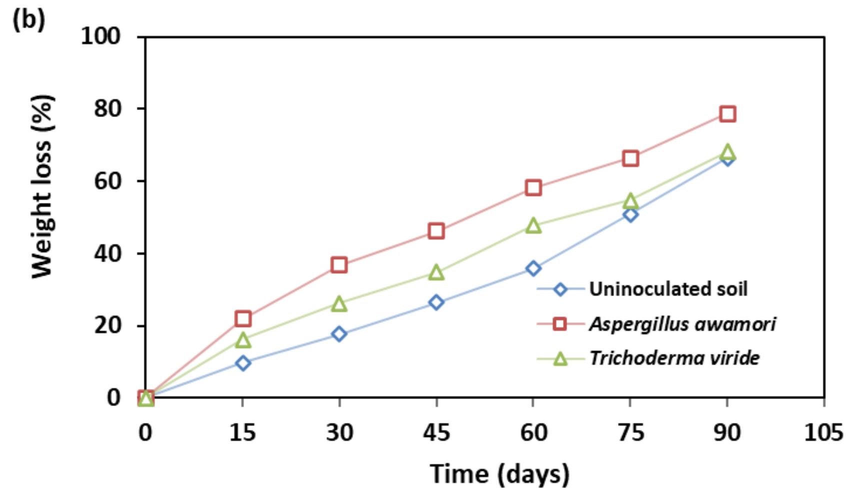


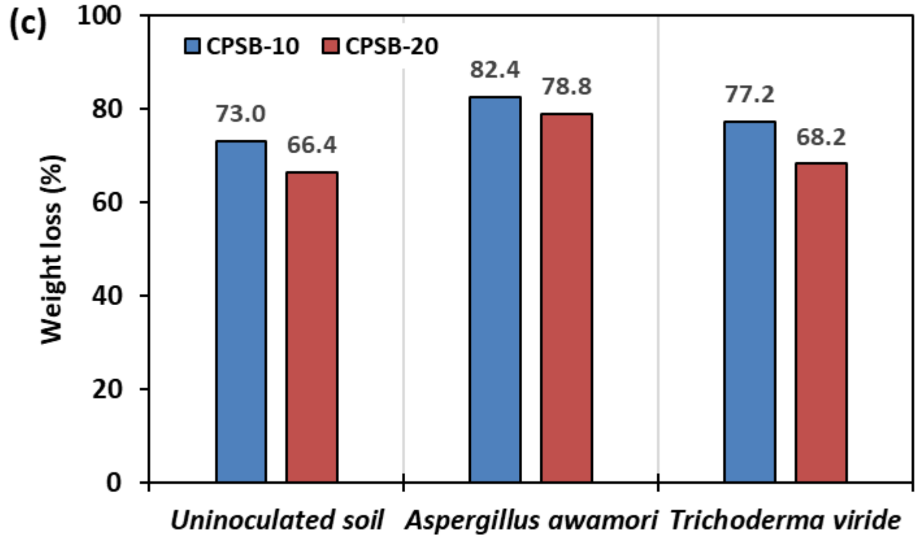


Coating materials	Uninoculated soil			Aspergillus awamori inoculation			Trichoderma viride inoculation		
	k (day^{-1})	$t_{0.5}$ (day)	R^2	k (day^{-1})	$t_{0.5}$ (day)	R^2	k (day^{-1})	$t_{0.5}$ (day)	R^2
CPSB-0	0.0257	27.0e	0.921	0.0339	20.4e	0.913	0.0281	24.7e	0.926
CPSB-5	0.0182	38.0d	0.964	0.0258	26.9d	0.935	0.0198	35.0d	0.946
CPSB-10	0.0134	51.9c	0.996	0.0185	37.4c	0.945	0.0173	40.1c	0.989
CPSB-15	0.0105	65.9b	0.998	0.0145	47.9b	0.955	0.0113	61.5b	0.988
CPSB-20	0.0094	74.1a	0.974	0.0136	51.1a	0.966	0.0097	71.5a	0.991

Weight loss pattern of CPSB-10 and CPSB-20 PVA/starch/bentonite polymeric blend

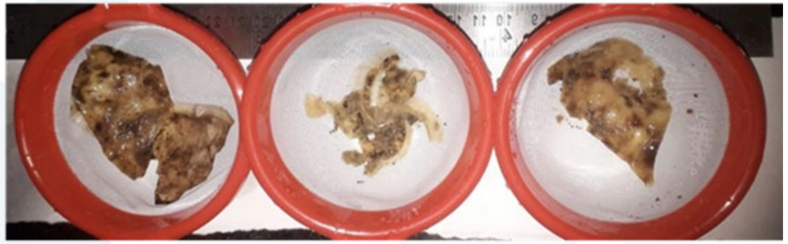






CPSB-10

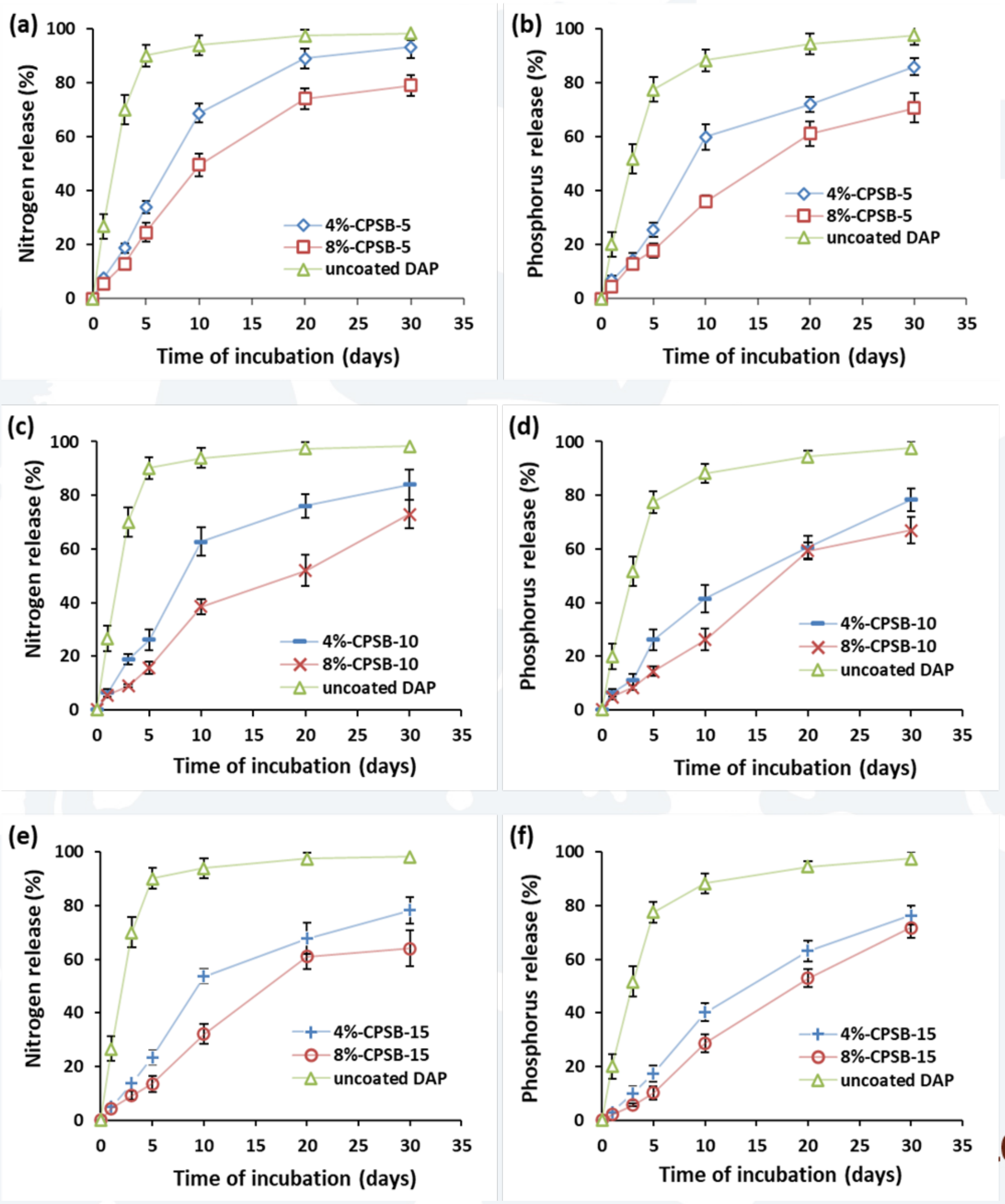
Before degradation



Uninoculated soil *Aspergillus awamori* *Trichoderma viride*

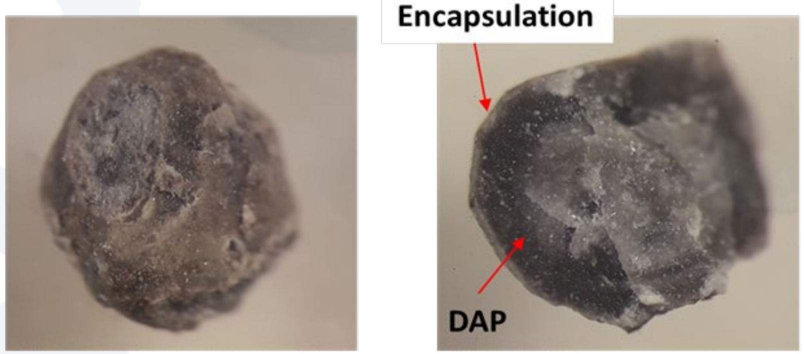
CPSB-10 after degradation

Nutrient release in water



Uncoated DAP

8%-CPSB-10 encapsulated DAP



Full grain

Fractured grain

Images of 8%-CPSB-10 encapsulated DAP under compound microscope

Modeled parameters

Different coated NP sources	N release				P release			
	n	K_m	R^2	Mechanism involved	n	K_m	R^2	Mechanism involved
4%-CPSB-5-DAP	0.76	0.77	0.985	Non-Fickian diffusion	0.72	0.73	0.950	Non-Fickian diffusion
8%-CPSB-5-DAP	0.84	0.39	0.972	Non-Fickian diffusion	0.78	0.41	0.986	Non-Fickian diffusion
4%-CPSB-10-DAP	0.76	0.68	0.972	Non-Fickian diffusion	0.73	0.62	0.945	Non-Fickian diffusion
8%-CPSB-10-DAP	0.78	0.41	0.946	Non-Fickian diffusion	0.78	0.36	0.956	Non-Fickian diffusion
4%-CPSB-15-DAP	0.79	0.42	0.973	Non-Fickian diffusion	0.93	0.16	0.979	Non-Fickian diffusion
8%-CPSB-15-DAP	0.82	0.35	0.963	Non-Fickian diffusion	0.97	0.10	0.955	Non-Fickian diffusion
Uncoated DAP	0.23	24.2	0.955	Quasi-Fickian diffusion	0.30	14.8	0.908	Quasi-Fickian diffusion

Incubation in soil

- Medium: Soil (Inceptisol and Vertisol)
- Products under evaluation: 7
- CPSB coated DAP (4%-CPSB-10-DAP, 8%-CPSB-10-DAP) and Uncoated DAP (reference)
- Temperature: 20 and 30 ^{0}C
- Targeted nutrients: Mineral nitrogen ($NH_4^+ + NO_3^-$) and Phosphorus
- Replication: 3
- Dose of P: 100 mg P kg^{-1} soil

❖ **Compared to Vertisol, N and P release from coated-DAP and uncoated DAP was higher in Inceptisol.**

❖ **At 30 ^{0}C, N release from coated-DAP and uncoated DAP was ~1.19 and 1.25 times higher than 20 ^{0}C.**

❖ **Whereas, P release was increased by ~1.04 times with increasing temperature (20 to 30 ^{0}C) during incubation.**

Details of pot-culture experiment

Pot experiment

Source of nutrients: 3 (4%-CPSB-10-DAP, 8%-CPSB-10-DAP and Uncoated DAP)

Types of soil: 2 (Inceptisol, New Delhi; Vertisol, Bhopal)

Weight of soil: 4 kg soil pot^{-1}

Fertilizer dose: 120:__:60 (N: P_2O_5: K_2O) kg ha^{-1} (excess nutrient supplied through Urea for N and MOP for K)

Set up: 1
Without *Aspergillus awamori*
Dose of P: 3
- **(i) 0 mg P kg^{-1}**
- **(ii) 25 mg P kg^{-1}**
- **(iii) 50 mg P kg^{-1}**

Set up 2:
With *Aspergillus awamori*
Dose of P: 1
- **(i) 25 mg P kg^{-1}**

Absolute control: One (without any nutrient supply)

Crop: Wheat (*Triticum aestivum* L.) var. HD-3086

Replication: 3; Design of experiment: CRD

Salient findings in pot-culture experiment

- The 8%-CPSB-10-DAP recorded comparatively higher grain yield (11.1 and 10.6 g pot^{-1} under Inceptisol and Vertisol, respectively);
- Compared to uncoated DAP it showed higher straw yield (~32 and 37%) and total biomass yield (~33 and 30%) in Inceptisol and Vertisol, respectively.
- Soils inoculated with Aspergillus awamori helped to produce ~7% higher grain yield than the uninoculated soils in both the soils (Inceptisol and Vertisol).
- Increased P doses resulted in significantly increased yield attributes and nutrient uptakes.
- Application of PVA/starch/bentonite polymeric blend coated-DAP increased the nutrient (mineral N and available P) supplying capacity even at 60 days after sowing than the uncoated DAP.
- With the application of PVA/starch/bentonite polymeric blend coated-DAP, the N recovery efficiency could be achieved up to 88% (44.9% for uncoated DAP); whereas, P recovery efficiency could achieved as high as 32.5% (15.2% for uncoated DAP).

Conclusions

- Bentonite incorporation is a good filler material to be used to prepare polymeric films to coat fertilizers.

- *Aspergillus awamori* could be a better option for decontamination of residual polymeric substances.

- Application of PVA/starch/bentonite polymeric blend coated-DAP increased the nutrient (mineral N and available P) supplying capacity even at 60 days after sowing than the uncoated DAP.

- Increased rate of coating will prolong nutrient release at slower rate.

- *Aspergillus awamori* inoculation during pot-culture experiment increased nutrient (P) availability for a longer period of time.

Thank you !