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Investigation of flowability and extrusion behavior of black soldier fly (*Hermetia illucens* L.) prepupal protein powder for 3D food printing applications

Running title: Printability of black soldier fly paste

Table S1. Preliminary rheological screening of gellan gum (GG) concentration and BSFP–GG base formulations for selecting the base composition used in the 3D-printable BSFP paste

Sample	BSFP (%)	GG (%)	Yield stress (Pa)	K	n	Decision
GG-0.25		0.25	0.15	0.12	0.55	Too weak support
GG-0.50		0.50	0.45	0.25	0.55	Selected balance
GG-0.75		0.75	1.21	0.44	0.56	High resistance
GG-1.00		1.00	2.12	0.70	0.58	Too stiff
B5-GG0.25	5.00	0.25	2.05	3.02	0.55	Low protein/weak support
B5-GG0.50	5.00	0.50	5.11	5.50	0.55	Extrudable but lower protein
B5-GG0.75	5.00	0.75	10.23	8.50	0.55	Stronger, lower protein
B7.5-GG0.25	7.50	0.25	8.01	8.09	0.56	Good, lower cohesion
B7.5-GG0.50	7.50	0.50	18.37	13.51	0.56	Optimum base formulation
B7.5-GG0.75	7.50	0.75	35.26	20.03	0.57	Too resistant
B10-GG0.25	10.00	0.25	30.12	19.27	0.57	High protein, resistant
B10-G0.50	10.00	0.50	55.17	30.13	0.58	High extrusion resistance
B10-G0.75	10.00	0.75	90.09	45.28	0.60	Too stiff/clogging risk

GG-0.25, GG-0.50, GG-0.75, and GG-1.00 represent GG-only samples containing 0.25, 0.50, 0.75, and 1.00% GG, respectively. B5, B7.5, and B10 indicate BSFP powder concentrations of 5.0, 7.5, and 10.0%, respectively, while GG0.25, GG0.50, and GG0.75 indicate GG concentrations of 0.25, 0.50, and 0.75%, respectively. K and n represent the consistency coefficient and flow behavior index, respectively.

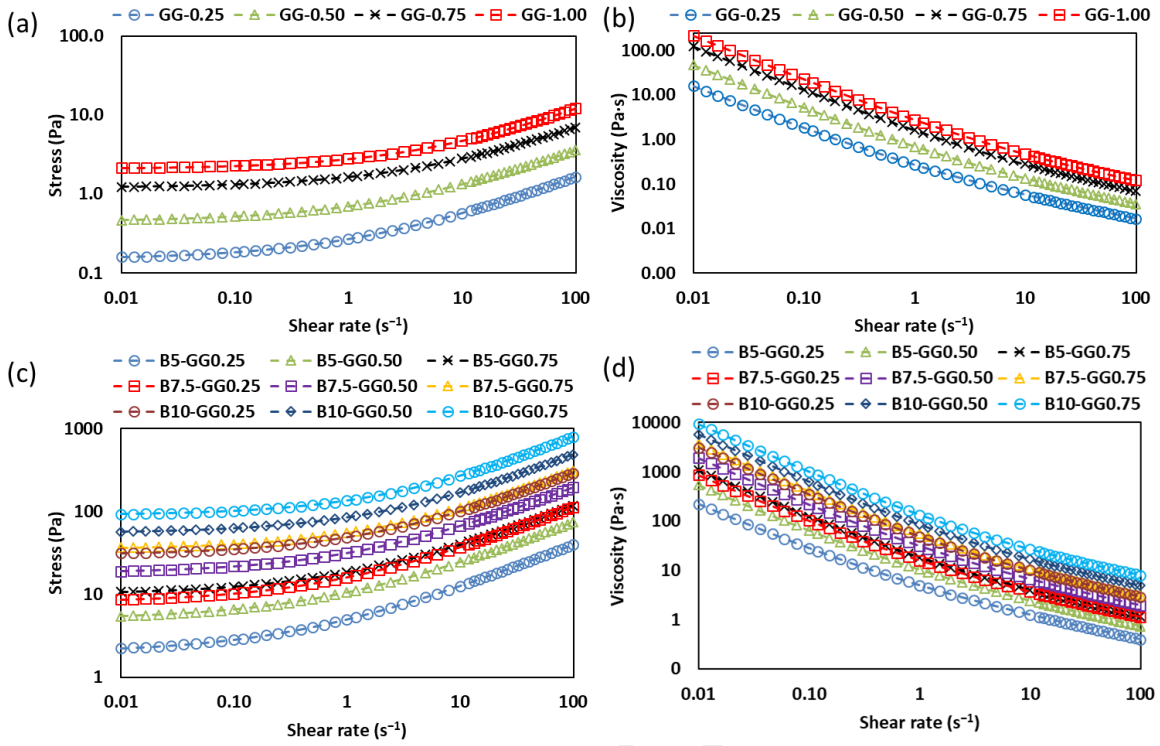

Figure S1. Preliminary rheological screening of gellan gum (GG) concentration and BSFP–GG base formulations for selecting the 3D-printable paste composition; (a) shear stress and (b) apparent viscosity of GG-only samples prepared at 0.25, 0.50, 0.75, and 1.00% GG, (c) shear stress and (d) apparent viscosity of BSFP–GG formulations prepared with different BSFP levels and GG concentrations.

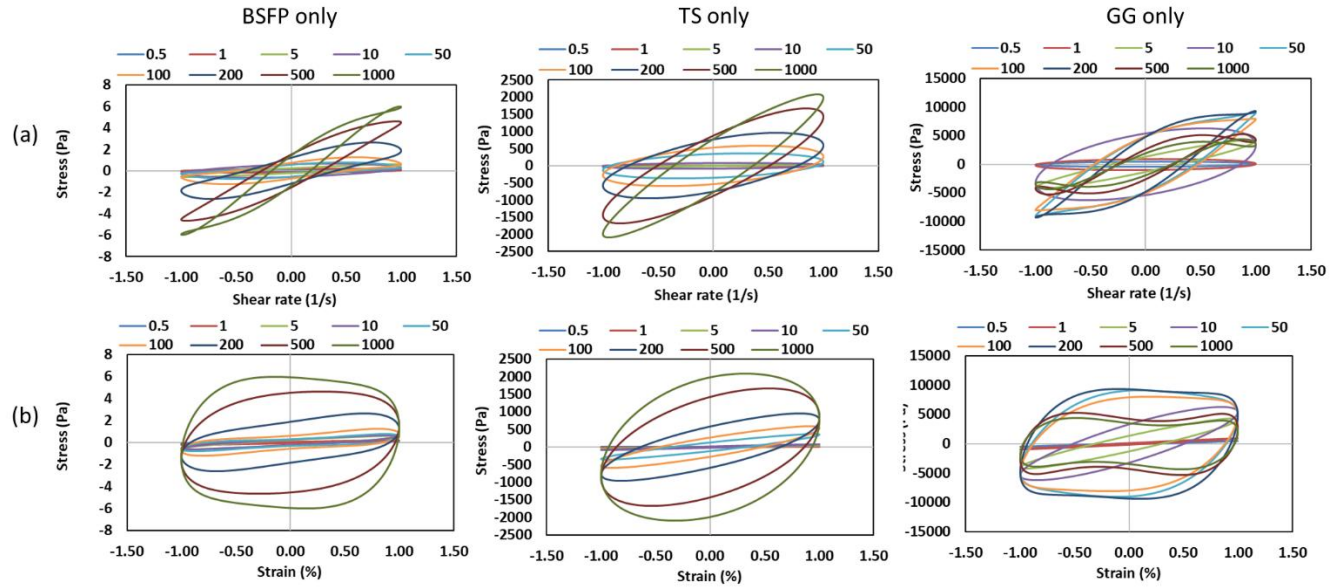

Figure S2. LAOS response of individual formulation components. (a) Stress–shear rate Lissajous curves and (b) stress–strain Lissajous curves of BSFP-only, TS-only, and GG-only samples measured at strain amplitudes of 0.5–1000%.

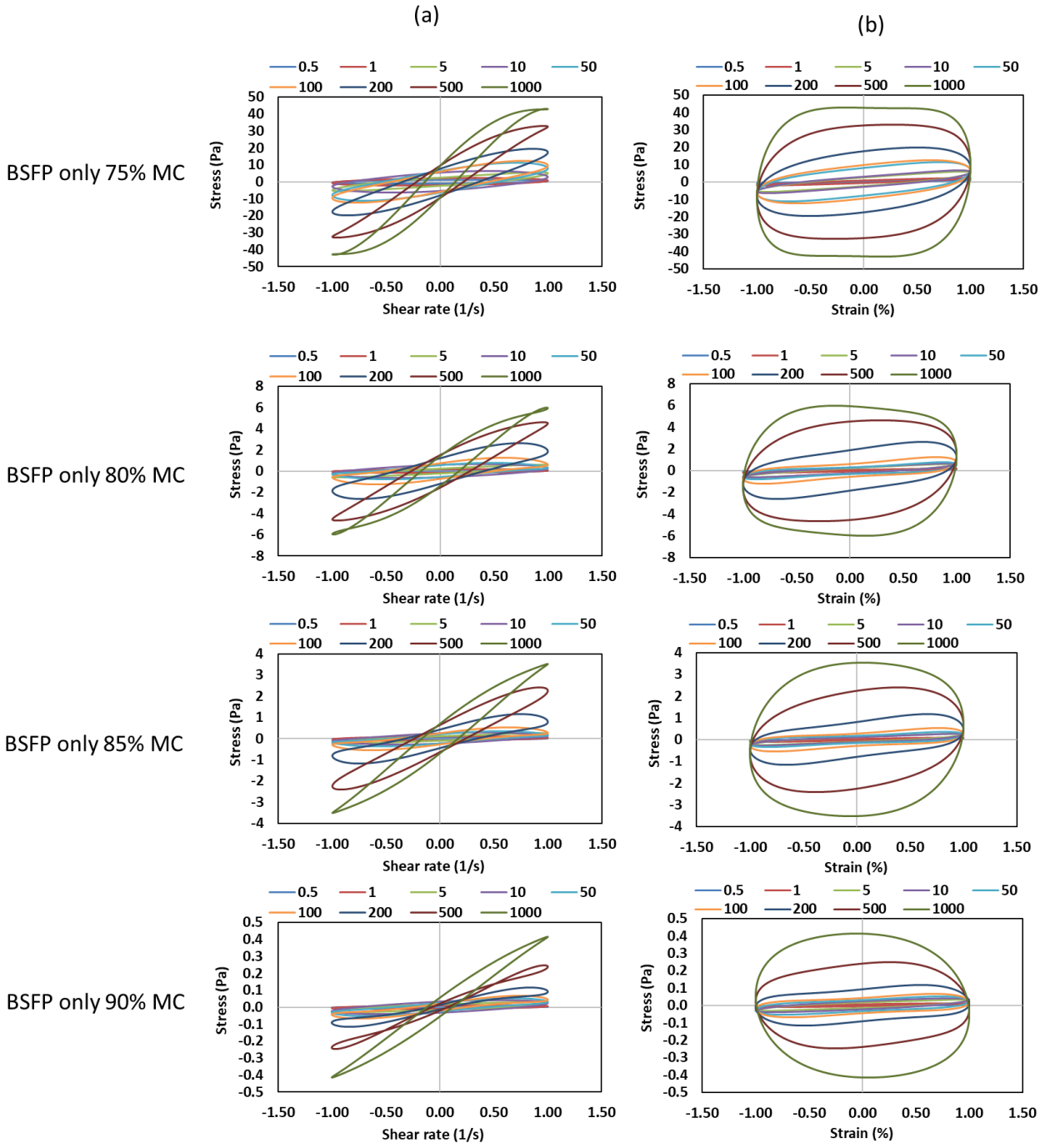

Figure S3. LAOS response of BSFP-only paste at different moisture contents. (a) Stress–shear rate Lissajous curves and (b) stress–strain Lissajous curves of BSFP-only samples prepared at 75, 80, 85, and 90% moisture content and measured at strain amplitudes of 0.5–1000%.

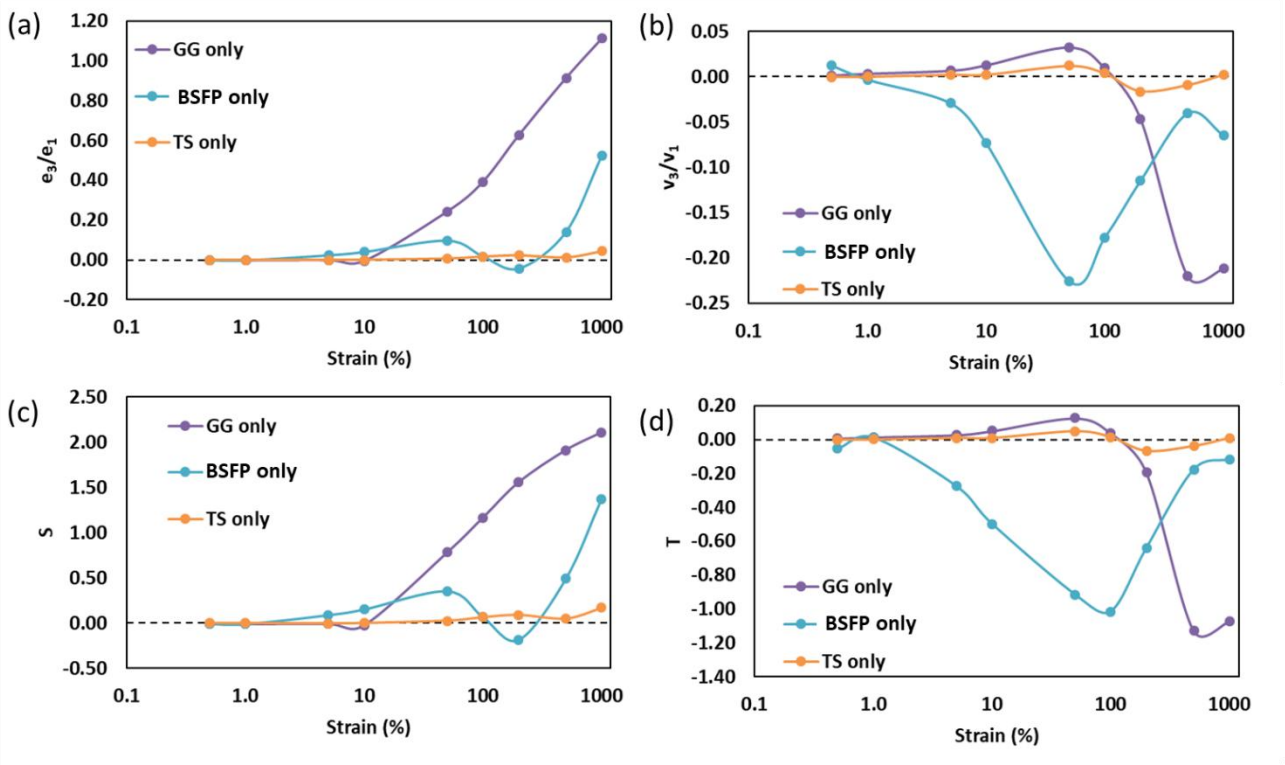

Figure S4. Chebyshev coefficient analysis of individual formulation components under large-amplitude oscillatory shear. (a) e_3/e_1; (b) v_3/v_1; (c) S, and (d) T values of GG-only, BSFP-only, and TS-only samples.

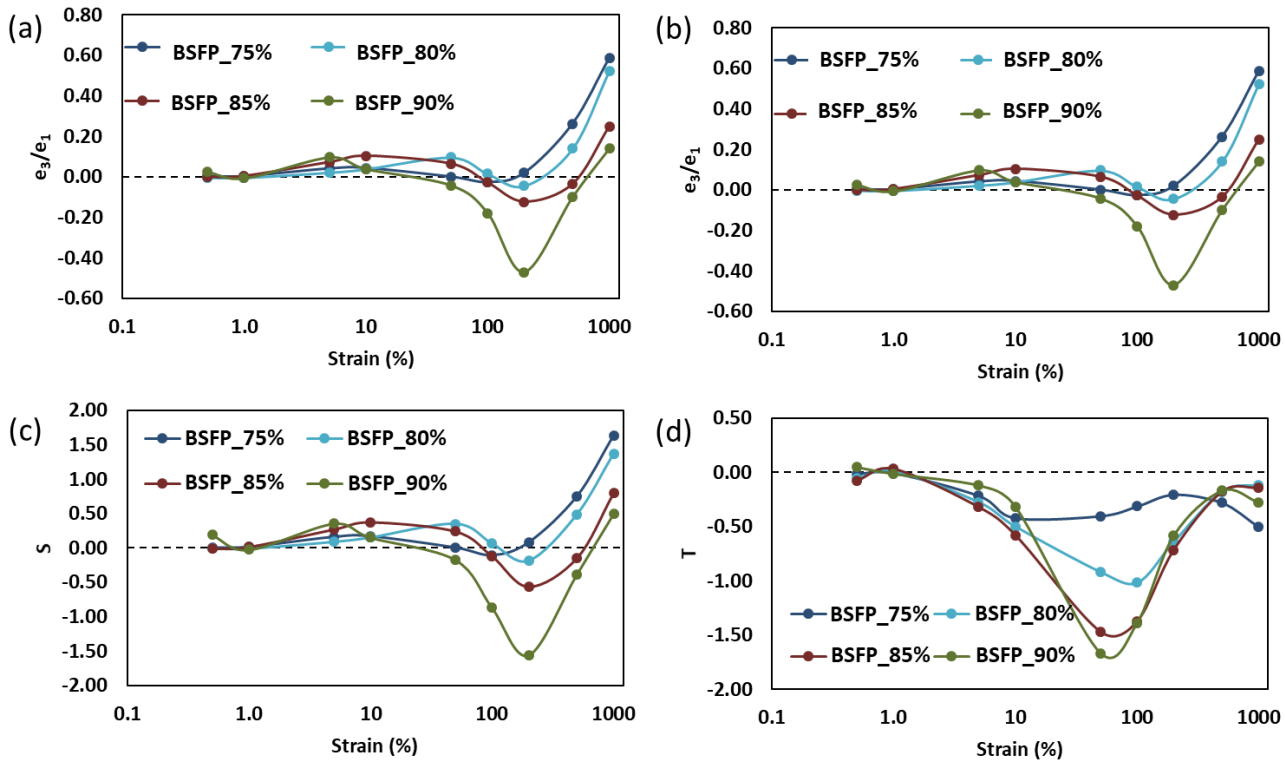

Figure S5. Chebyshev coefficient analysis of BSFP-only paste at different moisture contents under large-amplitude oscillatory shear. (a) e_3/e_1; (b) v_3/v_1; (c) S, and (d) T values of BSFP-only samples prepared at 75, 80, 85, and 90% moisture content.

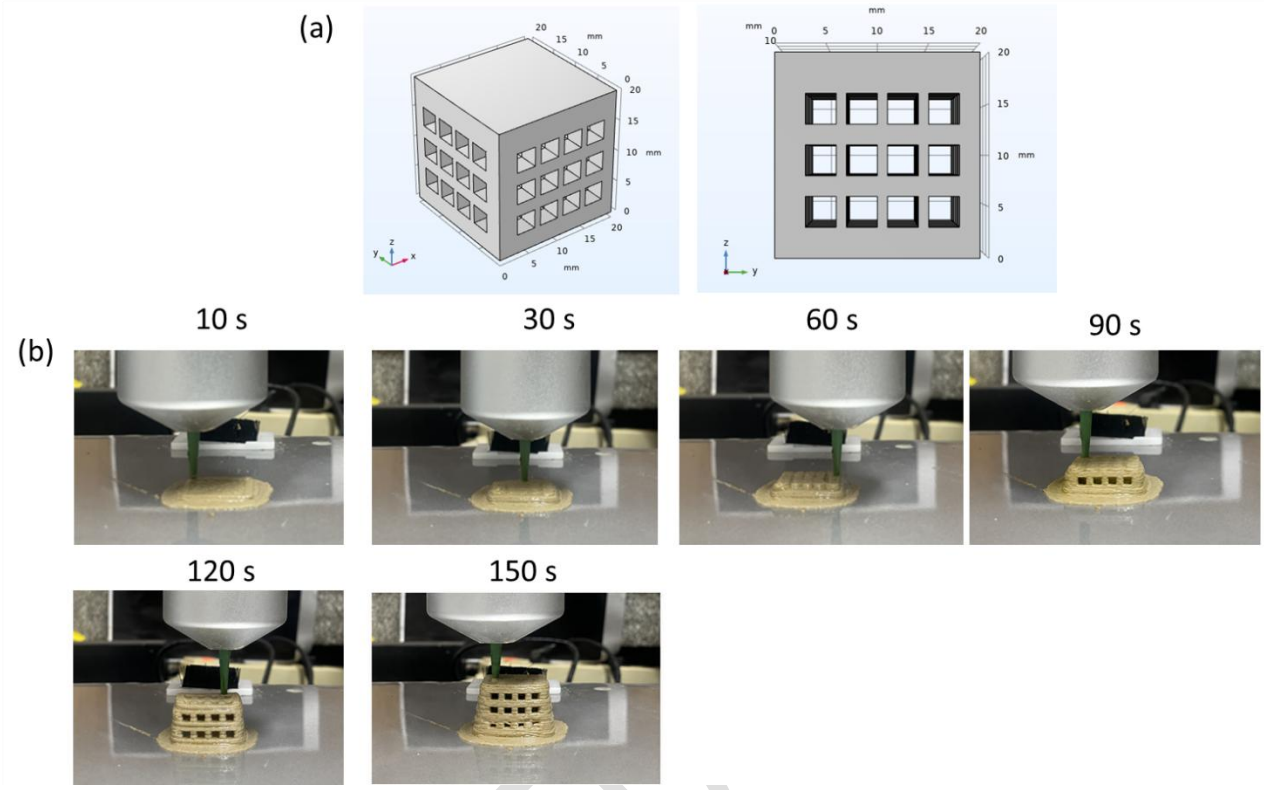

Figure S6. Validation of the direct ink writing performance of the selected BG-S2.5 formulation using a perforated 20 × 20 × 20 mm box model. (a) Three-dimensional and front-view representations of the designed model. (b) Time-sequence images captured during printing.