INFLUENCE OF 3D PRINTING TEMPERATURE ON THE COLORIMETRIC PROPERTIES OF SPIRULINA-PLA BASED FILAMENT

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ABSTRACT

3D printing is becoming a credible production technique on a larger scale, there is a need for development of sustainable and environmentally acceptable filaments. Unlike petroleum-based pigments or fillers commonly used to colour or reinforce 3D printing filaments, pigments derived from algae and biomass offer a lower environmental footprint and reduce reliance on synthetic additives. This study evaluates a 3D printing filament made as a biocomposite of 85% polylactic acid (PLA) and 15% spirulina. Both PLA and spirulina are biodegradable under appropriate composting conditions, improving the end-of-life profile of printed parts compared to conventional plastics derived from petroleum. Test specimens were printed at five nozzle temperatures (190 °C, 200 °C, 210 °C, 220 °C and 230 °C) under constant printing parameters, and the resulting colour changes were quantified using CIE$L^*a^*b^*$ colorimetry and total colour difference (ΔE^*_{00}). Surface gloss and roughness were also evaluated to correlate optical changes to print surface characteristics. These findings provide guidance for selecting printing temperatures that balance dimensional/mechanical print quality with preservation of the spirulina pigment's visual properties, which is relevant for aesthetic and functional applications of algae-based biocomposite filaments.

Keywords: 3D printing, biocomposite, color difference, filament, printing temperature

MATERIALS AND METHODS

Material: Commercial 3D printing filament with 85% PLA and 15% spirulina algae (SmartFil, SmartMaterials3d, Alcalá la Real (Jaén), Spain)
3D Printing: Original Prusa MK4S, with nozzle size 0.8 mm at five different nozzle temperatures (190 – 230 °C with 10 °C increments)
Sample dimensions: X = 40 mm, Y = 40 mm, Z = 3 mm, number of samples per temperature = 5
Microscopic images: Dino-Lite Pro AM413T at 25.2x magnification
Spectral analysis: Konica Minolta Spectrophotometer CM-3600d (10° observer angle and D65 illuminant)
Gloss: Elcometer 480T Glossmeter under 60° angle
Surface roughness: MarSurf PS 10 profilometer with 2 µm probe tip (along the printing lines – parallel, and perpendicular to the printng lines). Settings: Lt = 4.8 mm (traversing length); Measurement force of 7.5 × 10−4 N; Number of sampling lengths = 5; Measuring speed = 0.5 mm/s;

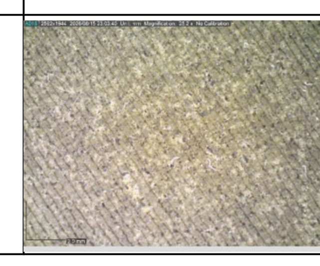
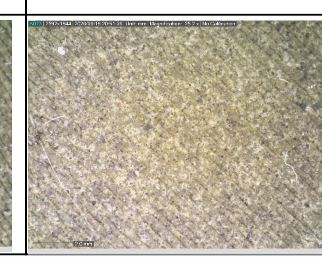
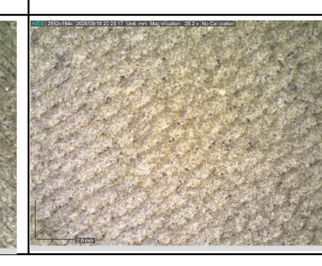
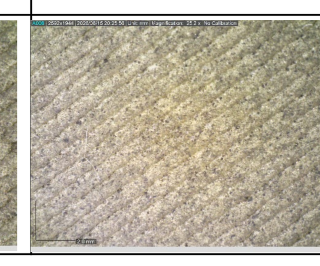
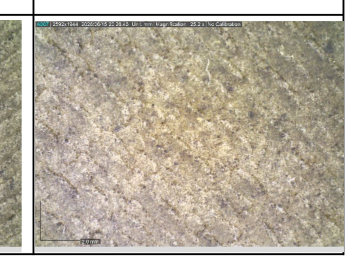
Temperature	190 °C	200 °C	210 °C	220 °C	230 °C
Sample					

Figure 1. Photographs of 3D printed samples in different temperatures under 25.2x magnification

RESULTS

Figure 1. shows the visual results of fused deposition 3D printing samples used in this research. Images show the printing lines that are more distingushed at lower temperatures (190 °C). With increasing temperatures, borders between printing lines are more dissolved creating different surface effects.

SPECTRAL ANALYSIS - CIE $L^*a^*b^*$

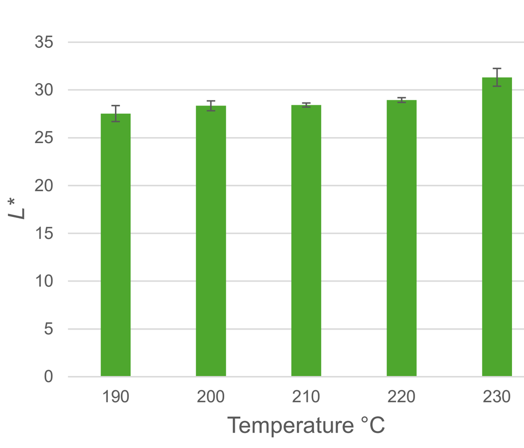


Figure 2. Lightness parameter

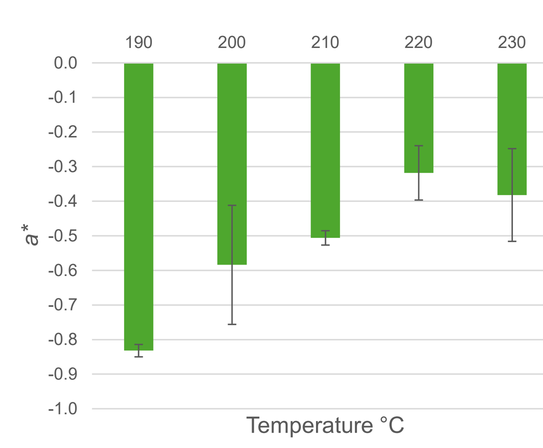


Figure3. Red-green parameter

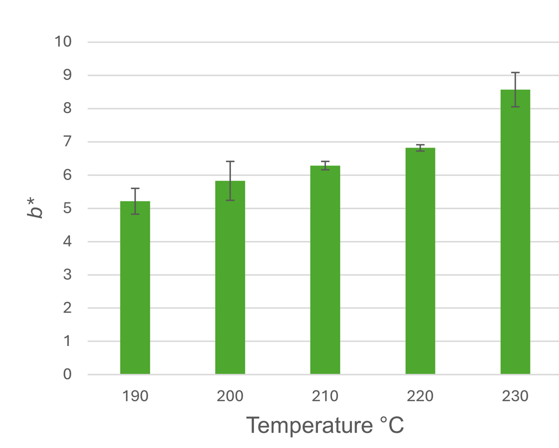


Figure 4. Yellow-blue parameter

- Lightness parameter (Figure 2.) L^* rises monotonically (27.5 → 31.3), a ~13.8% increase in lightness across the range, with the sharpest jump between 220 °C and 230 °C.
- Red-green axis (Figure 3.) a^* moves from slightly negative (green-leaning, −0.83) toward near-neutral (−0.32 to −0.38), i.e., the green cast weakens with temperature; note the small non-monotonic dip at 230 °C, which is within the reported uncertainty (±0.13) and likely not meaningful.
- Yellow-blue axis (Figure 4.) b^* rises monotonically and proportionally more (5.21 → 8.57, ~65% increase), indicating a clear shift toward yellow.

SPECTRAL ANALYSIS - COLOUR DIFFERENCE ΔE^*_{00}

- At **200 °C** (ΔE^*_{00} = 0.87): below/at the ~1.0 just-noticeable-difference threshold, colour difference is not perceptible to an untrained observer.
- At **210–220 °C** (ΔE^*_{00} = 1.20–1.83): colour difference is perceptible only on close inspection range.
- At **230 °C** (ΔE^*_{00} = 3.96): a clearly visible color shift relative to the 190 °C baseline.

Table 1. Colour difference ΔE^*_{00} between printed samples

T °C	ΔE^*_{00} (vs. 190 °C)
200	0.87
210	1.20
220	1.83
230	3.96

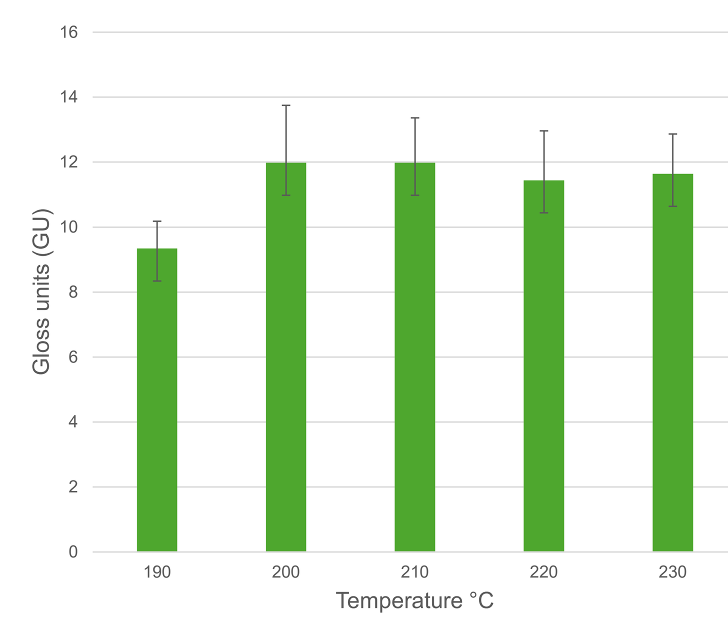


Figure 5. Gloss measurments at 60° angle

GLOSS

- Samples printed at **200 °C** and above show roughly the same amount of gloss from 11.44 – 11.98 GU
- At **190 °C** value is slightly less than 10 GU which places those samples in the matte or lower ranges of semi-gloss classification.
- Low gloss (~10 GU) on FDM-printed PLA-organic composites is consistent with expectations.

Table 2. Surface roughness measurments parallel and perpendicular to printed lines

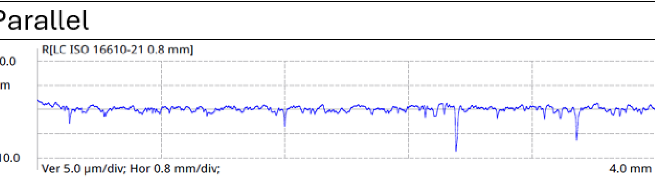
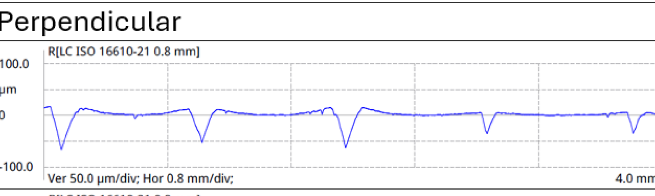
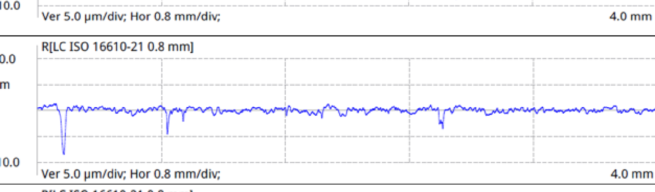
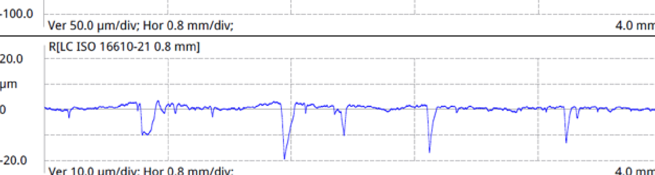
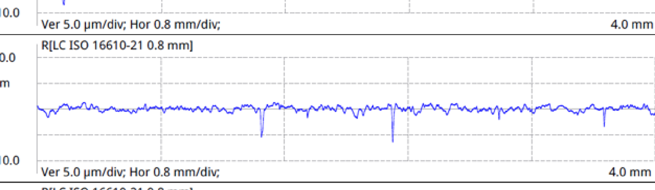
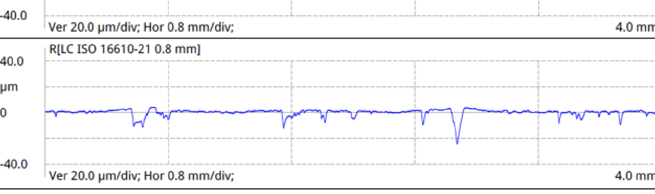
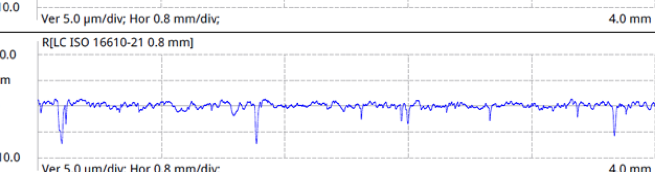
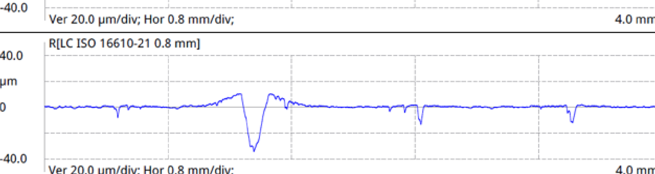
T°C	Ra (µm)	Rz (µm)	Rmax (µm)
Parallel			
190	3.50 ± 4.18	19.07 ± 18.18	28.82 ± 24.63
200	0.63 ± 0.26	6.70 ± 3.37	14.03 ± 7.30
210	0.58 ± 0.38	5.17 ± 2.98	9.95 ± 8.27
220	0.50 ± 0.13	5.79 ± 2.28	11.09 ± 4.79
230	0.86 ± 0.64	9.60 ± 5.59	16.68 ± 15.12
Perpendicular			
190	6.69 ± 3.36	58.27 ± 23.82	76.95 ± 31.84
200	1.49 ± 0.68	18.99 ± 6.71	29.25 ± 14.73
210	0.94 ± 0.24	11.34 ± 2.30	17.76 ± 4.74
220	1.07 ± 0.33	11.92 ± 2.54	19.67 ± 6.59
230	1.20 ± 0.54	11.92 ± 4.49	23.59 ± 13.33

R_a—the arithmetic average of the profile's deviation;
R_z—the height of the profile's irregularities at 10 points; and
R_{max}—the greatest height of the profile

SURFACE ROUGHNESS

- **190 °C**: highest roughness and largest variability (e.g., Rz = 58.27 ± 23.82 µm perpendicular). This is consistent with insufficient melt viscosity reduction, leading to poor inter-bead coalescence, incomplete wetting between adjacent roads, and irregular bead geometry.
- **200–220 °C**: roughness minimum, suggesting this is near the optimal processing window where melt flow is sufficient for good road fusion without excess material spread.
- **230 °C**: modest rebound, plausibly linked to over-extrusion, oozing/stringing, or the onset of thermal degradation increasing melt instability

Table 3. Comparison of surface morphology of measurments taken parallel and perpendicular to printed lines

T °C	Parallel	Perpendicular
190		
200		
210		
220		
230		

CONCLUSIONS

- Spectral analysis shows expected colour degradation in the green and especially in the blue part of the CIE $L^*a^*b^*$ colour space due to algal filler and PLA thermal degradation.
- Colour difference increases as expected with higher temperatures in relation to initial 3D printing temperature.
- Low values of gloss indicate matte surface, slightly rising with increasing temperature toward semi-gloss. The parallel layer lines of 3D printing light scattering is diffused rather than specular, and organic filler particles (e.g., algal biomass) further roughen the surface at the microscale, both of which suppress specular reflectance.
- Surface roughness decreases with temperature due to greater melting
- Roughness along the printing lines (parallel) is significantly lower and less variable than roughness measured perpendicular to the printing lines.

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