Supporting Information

Table S1. Comparative dyeing performance and fastness properties of Alpaca yarns dyed with Indigo Carmine under different mordanting conditions

Treatment	Rubbing fastness		Washing fastness						Color change	Sample
	Dry	Wet	CA	CO	PA	PES	PAN	WO		
T-1	4	3/4	4/5	3/4	4	4/5	4/5	4	2/3	
T-2	3	4	4/5	3/4	4	4/5	4/5	3	3	
T-3	3	3/4	4/5	4/5	4	4/5	4/5	4	4	

T-1, dyeing with no mordant; T-2, dyeing with citric acid; T-3, dyeing with potassium alum. Standard textile fiber codes: CA = Acetate, CO = Cotton, PA = Polyamide (Nylon), PES = Polyester, PAN = Acrylic, and WO = Wool.

The results indicate that the treatment T-1 yields lower fastness values and weaker color depth. For treatment T-3, a conventional metallic mordant, improved both fastness and color intensity due to its ability to form coordination complexes with the dye and the fiber [1,2]. However, its use was intentionally excluded from the main experimental design, as this study aimed to develop environmentally friendly and metal-free dyeing strategies.

Treatment T-2, a biodegradable organic acid, yields a satisfactory improvement in dye performance compared to the control (T-1). While organic acids like citric acid do not form coordination complexes in the same way as metal salts (T-3), they may enhance dye affinity by modifying the fiber surface or influencing the ionic environment of the dye bath [3].

Table S2. Assignments dyeing condition of the Alpaca dyeing process using Indigo carmine.

No.	Coded	Mordant concentration (g/L)	Dyeing temperature (°C)	Exhaust time (min)
1	T1	2	85	30
2	T2	4	85	30
3	T3	2	95	30
4	T4	4	95	30
5	T5	2	85	60
6	T6	4	85	60
7	T7	2	95	60
8	T8	4	95	60
9	T9	1.31821	90	45
10	T10	4.68179	90	45
11	T11	3	81.591	45
12	T12	3	98.409	45
13	T13	3	90	19.7731
14	T14	3	90	70.2269
15	T15	3	90	45
16	-	3	90	45
17	-	3	90	45
18	-	3	90	45
19	-	3	90	45
20	-	3	90	45

References

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