CHEMICAL ENGINEERING TRANSACTIONS
VOL. 59, 2017
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet
Guest Editors: Zhuo Yang, Junjie Ba, Jing Pan

ISBN 978-88-95608- 49-5; **ISSN** 2283-9216
DOI: 10.3303/CET1759123

The Optimized Analysis of the Dyeing Property of Coptis Chinensis towards Natural Bamboo Fiber

Hong Chen[a], Mohan Zhang[a], Hong Liu[b]*

[a]Clothing and Design Faculty, Minjiang University, Fuzhou 350108, China
[b]School of Fashion, Henan University of Engineering, Zhengzhou 451191, China
liuhong329@163.com

The paper researches the dyeing property of coptis chinensis and bamboo fiber through orthogonal experimental analysis and single factor comparative analysis, gets the optimized process of direct dyeing, pre-mordant dyeing, one-bath dyeing and post-mordant dyeing, as well as tests and compares the dyeing fastness and fracture tensile property of the optimized process of the four dyeing methods.

1. Introduction

Coptic Chinensis is a Chinese medicinal herb, with the functions of clearing heat and purging fire, removing dampness, relieving internal fever, fighting a wide range of bacteria, and reducing blood sugar. The main active ingredients in coptis chinensis, such as berberine, coptisine, methyl berberrubine, alkaloids, belong to alkaloids natural pigments. Therefore, coptis chinensis is also a natural dyestuff. Dyeing the natural bamboo fiber with coptis chinensis extract, not only ensures the quality of pure natural bamboo fiber, but also improves the added value of the products, bring bamboo fiber the function of health care, as well as comfortable and safeness for wearing.

2. Experimental Results and Analysis

2.1 Orthogonal Experiment of Coptis Chinensis Dyeing

Each factor that affects the coptis chinensis dyeing has been designed into an orthogonal test table consisting of 3 levels and 4 factors to do the orthogonal experiments. The bath ratio is 1:40, the mass of fiber is 0.4g, the design and results of the orthogonal experiment are as follows:

2.1.1 Direct Dyeing

Take the dyeing temperature, dyeing extract dosage, pH value and Nacl dosage as the main factors influencing the dyeing process to design the orthogonal test table. Carry out orthogonal tests according to the table with the bath rate of 1:50 and the dyeing extract dosage of 20ml, the results are as shown in Table 1.
From the R range analysis of Table 1, it is found that the order of the influences the factors have in direct dyeing on the dye-uptake is A>B>C>D respectively, while the order of the influences on the degree of fixation is A>C>D>B respectively, which means that, the dyeing temperature has the most significant influence on the dyeing effect in direct dyeing, followed by the pH value of the dye liquor and dosage of Nacl, while dyeing time has the least influence on dyeing effect. According to the value of K of each factor and judging by the dye-uptake of the fiber, the best technique is: A3 B1 C3 D1; judging by the degree of fixation of the fiber, the best technique is: A3 BC1 D3 B3. Combing both the two factors, the best technique is: A3 B2 C3 D1, which is, the dyeing temperature being 70°C, the pH value being 6, the dosage of Nail being 2.5g/L, and the dyeing time being 30min. (Kalla et al., 2015)

Please cite this article as: Hong Chen, Mohan Zhang, Hong Liu, 2017, The optimized analysis of the dyeing property of coptis chinensis towards natural bamboo fiber, Chemical Engineering Transactions, 59, 733-738 DOI:10.3303/CET1759123

Table 1: The Orthogonal Experimental Results of Direct Dyeing

EXPNO	A Dyeing temperature (°C)	B Dyeing time (min)	C PH range	D Mordant dosage (%)	Dye-uptake	Fixation rate
1	50	6	1.5	30	13.91	2.75
2	50	8	2.0	45	10.86	3.25
3	50	11	2.5	60	11.45	3.75
4	60	11	2.0	30	16.69	11.00
5	60	8	1.5	45	18.64	2.50
6	60	6	2.5	60	16.38	13.00
7	70	11	2.5	30	17.33	8.50
8	70	6	1.5	45	17.65	17.75
9	70	8	2.0	60	17.36	13.75
Dye-uptake	K_1	12.073	17.310	16.640	16.637	
	K_2	17.563	16.050	14.970	16.517	
	K_3	19.113	15.390	17.140	15.597	
	R	7.040	1.920	2.170	1.040	
Fixation rate	K	3.250	7.417	11.167	6.333	
	K	8.833	7.833	9.333	8.250	
	K	13.333	10.167	4.197	10.833	
	R	10.083	2.750	6.250	4.500	

2.1.2 Mordant Dyeing

Take the dyeing temperature, dyeing time, pH value and mordant dosage as the influencing factors to design a L9(34) orthogonal experiment, and carry out pre-mordant dyeing, one-bath dyeing and post-mordant dyeing respectively. Considering the conflicts between the toxicity of some metal ions and the study on natural dyestuff, alum (KAL (SO2)2-12H2 O) is used as the mordant (Sivakumar A. et al., 2015).

a) Pre-mordant Dyeing

Pre-mordant dyeing method: after wetting the fabric, put it in the solution which contains alum mordant to process; after 20min, take it out and put it in the dye bath with natural plant dyestuff; use it for all kinds of index testing after the post-processing of dyeing. Technological process: mordant treatment—rinsing and dyeing. The experimental results are as shown in Table 2.

Table 2: The Orthogonal Experimental Results of Adopting Mordant before Dyeing

EXPNO	A Dyeing temperature (°C)	B Dyeing time (min)	C PH range	D Mordant dosage (%)	Dye-uptake	Fixation rate
1	50	30	6	3	14.81	4.00
2	50	45	8	6	12.39	2.50
3	50	60	11	9	10.21	3.50
4	60	30	11	9	18.44	8.75
5	60	45	8	3	18.21	12.25
6	60	60	6	6	16.78	8.50
7	70	30	11	6	19.79	13.00
8	70	45	6	9	20.34	12.75
9	70	60	8	3	16.44	14.25
Dye-uptake	K_1	12.470	17.680	17.310	16.487	
	K_2	17.810	16.980	15.757	16.320	
	K_3	18.857	14.477	16.070	16.330	
	R	6.387	3.203	1.553	0.167	
Fixation rate	K_1	3.333	8.583	8.417	10.167	
	K_2	9.833	9.167	8.500	8.000	
	K_3	13.333	8.750	9.583	8.333	
	R	10.000	0.584	1.166	2.167	

Based on the analysis of range R of Table 2, under the pre-mordant condition, it is found that the order of the influences the factors have on the uptake rate in the orthogonal experiment is A>B>C>D respectively, and the order of the influences on the fixation rate is A>D>C>B respectively. Similar to direct dyeing, according to the K value of each factor and judging by the dye-uptake of fiber, the best process is: A3 B1 C1 D1 ; judging by the fixation rate of fiber, the best process is: A3 D1 C3 B2 . Combining the two factors, the best technique of pre-mordant dyeing is determined as: A3 B1 C1 D1, which is the dyeing temperature being 70 °C, the dyeing time being 30min, the pH value being 6, and the mordant dosage being 3%. (Rico-Ramirez et al., 2010)

b) One-bath Mordant Dyeing

The one-bath dyeing method: after wetting the natural bamboo fiber, put it into a dye bath containing mordant and natural plant dyestuff. After being dyed, the natural bamboo fiber is taken out for reprocessing, and all performance tests are carried out. The experimental results are as shown in Table 3.

*Table 3: The Orthogona*l Experiment Results of One-bath Mordant Dyeing

EXPNO	A Dyeing temperature (°C)	B Dyeing time (min)	C PH range	D Mordant dosage (%)	Dye-uptake	Fixation rate
1	50	30	6	3	12.41	3.50
2	50	45	8	6	13.55	3.75
3	50	60	11	9	11.78	3.43
4	60	30	11	9	12.67	7.25
5	60	45	8	3	16.55	11.00
6	60	60	6	6	17.39	21.50
7	70	30	11	6	20.72	10.75
8	70	45	6	9	23.44	15.00
9	70	60	8	3	21.27	10.50

Dye-uptake	K_1	12.580	15.267	17.747	16.743
	K_2	15.537	17.847	15.830	17.220
	K_3	21.810	16.813	16.350	15.963
	R	9.230	2.580	1.97	1.357
Fixation rate	K_1	3.567	7.167	13.333	8.333
	K_2	13.250	9.917	7.167	12.000
	K_3	12.083	11.817	8.400	8.567
	R	9.683	4.650	6.166	3.667

According to the analysis of range R of Table 3, under the condition of one-bath mordant, the influence of all factors in the orthogonal experiment on dye-uptake in order is: A>B>C>D and on the fixation rate is A>C>B>D. Similar to the dyeing method above, according to the value of K of each factor, judged by the up-take rate, the best technique is: A3 B2 C1 D2 ; Judged by the degree of fixation, the best technique is:A3 B1 C3 D2 . Synthesizing the two factors, we concluded that the optimum techniques for the metachrome process are as follows: A3 B2 C1 D2, which indicates that the dyeing temperature is 70 °C and the dyeing time is 45 min. The pH value shall be 6 and mordant dosage 6%.

c) Afterchromed dyeing

The wetted bamboo fiber is put into a dye bath containing natural plant dyes. Dye after changing the orthogonal factors. The mordant will be added after finishing dyeing and 30 min later, the indicators can be tested after the mordant is treated.

Technological process: dyeing, washing. Mordant treatment, washing. The experimental results are shown in Table 4.

It is known from the range R analysis in Table 4, under the post-mordant condition, the influencing extent of all factors to the dyeing rate in the orthogonal experiment is A>B>C>D, the influencing extent of them to the fixation rate is A>D>B>C, that is to say, the influence of dyeing temperature to the dyeing result is the most significant, the second one is the bathing time, while the influence of pH value and mordant dosage to the dyeing effect is less. According to the K value of each factor, evaluated on the basis of dyeing rate of fiber, the best process is: A3 B2 C1 D2 ; Judged by the fixation rate of fiber, and the best process is: A3 D1 B2 C3 . Synthesizing two factors, the best one-bath mordant dyeing process is concluded: The best mordant dyeing

process is: A3 B2 C1 D2, which means the dyeing temperature is 70, the dyeing time is 45 minutes, the pH value is 6 and the dosage of mordant is 6%.

Table 4: The orthogonal experiment results of post-mordant dyeing

EXPNO	A Dyeing temperature(°C)	B Dyeing time (min)	C PH range	D Mordant dosage(%)	Dye-uptake	Fixation rate
1	50	30	6	3	13.68	4.50
2	50	45	8	6	14.30	5.25
3	50	60	11	9	12.92	5.40
4	60	30	11	9	14.45	5.00
5	60	45	8	3	17.88	13.75
6	60	60	6	6	18.73	6.25
7	70	30	11	6	21.34	6.25
8	70	45	6	9	23.59	13.00
9	70	60	8	3	22.61	19.25
Dye-uptake	K_1	13.633	14.490	18.667	17.990	
	K_2	17.020	18.590	17.053	18.123	
	K_3	22.447	18.020	17.380	16.987	
	R	8.814	2.100	1.614	1.136	
Fixation rate	K_1	5.050	7.500	8.000	12.500	
	K_2	8.333	10.750	9.833	8.167	
	K_3	15.167	10.300	10.717	7.883	
	R	10.117	3.250	2.717	4.617	

2.2 Comparison of Staining Methods

The bamboo fibers were dyed according to the best processes of dyeing methods above. The dyeing rate and fixation rate were measured and results are shown in Table 5.

Table 5: Comparison of Dyeing Effects of Four Dyeing Methods

Staining method	Direct Dyeing	Pre-mordant Dyeing	One-bath dyeing	Post-mordant Dyeing
Dye-uptake rate/%	19.65	22.34	20.67	20.37
Degree of fixation/%	15.75	20.37	18.50	19.56

We can see from table 4 that there is great difference among the dyeing effects of the 4 different dyeing methods to the bamboo fiber, mordant dyeing has a larger dye-uptake and fixation rate than the direct dyeing, which demonstrates that mordant dyeing could make a deeper color of the fiber, the visual mordant dyeing method could make the color of bamboo fiber deeper and better contrasting with that of the direct dyeing method. This is because that the aluminum mordant can enter the fiber, form a reaction in the fiber, so as to improve the rate of dyeing, while among the mordant dyeing, the dyeing effect of the pre-mordant is better than that of one-bath dyeing and post-mordant dyeing, indicating that the natural vegetable dye, Coptis chinensis, it is suitable to adopt the pre-mordant dyeing method in staining bamboo fiber (Lee et al., 2017).

3. Test of colour fastness to dyeing fibre after coptis dyeing

Colour fastness is one of the important indexes of judging dyeing product quality, which is extremely important for evaluating the dyeing of natural plant dyestuff. Color fastness to perspiration and soaping of four optimal dyeing methods are shown in Table 6:

As seen from Table 6, after being dyed by the natural plant dyestuff Coptis, the bamboo fiber had a good color fastness to soaping, which reached grade 3 or above. Whether it is mordanted or soaped, its soaping fastness was greatly improved as compared with the direct dyeing. However after dyeing with natural vegetable dyestuff Coptis chinensis, the color fastness to perspiration of original bamboo fiber is relatively poor, which is completely below Grade 3. Whether it is through direct dyeing or mordant dyeing, the fastness to perspiration is poor.

Table 6: Comparison of the colour fastness of different dyeing methods

Staining Method	Degree/grade of soaping color fastness		Degree/grade of color fastness to perspiration			
			Alkaline perspiration		Acidic perspiration	
	Original sample discoloration	Cotton staining	Original sample discoloration	Cotton Staining	Original sample discoloration	Cotton Staining
Direct dyeing	3	3-4	2-3	2-3	2-3	2
Pre-mordant Dyeing	3	3-4	2-3	2-3	2-3	2-3
One-bath dyeing	3-4	4	2	2-3	2	2-3
Post-mordant dyeing	3-4	3-4	2	2-3	2	2-3

Note: Soaping after dyeing refers to the process in which the bamboo fiber first go through all kinds of dyeing and then be treated with soaping.

4. Breaking property testing of the dyeing fiber dyed by coptis chinensis

The breaking strength and elongation is also one of the important factors for measuring products dyeing quality. To test breaking strength and elongation of byeing bamboo fiber to prove that the dyeing effect on mechanical properties of dyeing fiber is particularly important for the evaluation of dyeing of natural plant dyes. 4 methods for dyeing bamboo fiber: pre-dyeing breaking strength, post-dyeing breaking strength, pre-dyeing breaking elongation and post-dyeing breaking elongation, see Table 7.

Table 7: Breaking property of bamboo fiber before and after dyeing by coptis chinensis

Dyeing method		Direct dyeing	Pre-mordant dyeing	Apposition dyeing	Post-mordant dyeing
Before bleaching	Breaking strength (context)	3.93	3.93	3.93	3.93
	Elongation /%	12.38	12.38	12.38	12.38
After bleaching	Breaking strength (context)	3.88	3.88	3.88	3.88
	Elongation/%	11.86	11.86	11.86	11.86
After dyeing	Breaking strength (context)	4.09	4.22	4.11	4.19
	Elongation/%	3.5	4.3	3.9	2.3

Note: During the process of testing single fiber, it is discovered that the strength unevenness of bamboo fiber is on the high side. The key reason is that bamboo fiber has obviously uneven thickness. (Park et al., 2013)

According to Table 7, the breaking strength of all bamboo fibers dyed by coptis chinensis increases, especially after mordanting, the breaking strength of bamboo fibers is relatively stronger than that after direct dyeing; But the breaking elongation of bamboo fiber after dyeing accordingly turns small, the reason may be that after dyeing, the mechanical property structure of bamboo fiber is broken, resulting in the decrease of breaking elongation.

5. Conclusion

Coptis chinensis has best dyeing effect by using pre-mordant dyeing. Apposition dyeing can be used to dye bamboo fiber. Temperature and PH value have the biggest effect on the dyeing rate and the fixation rate. The dyeing temperature should not be too high, and the PH value should be controlled between 9 and 11.

Through orthogonal test and extreme difference analyzing, the best pre-mordanting process of coptis chinensis to bamboo fiber is: A3 D1 C3 B2. Combining the two factors, the best process is: A3 D1 C3 B2. Combining the two factors, the best pre-mordanting process is: A3 B1 C1 D1, namely, the dyeing temperature is 70 °C, the dyeing time is 30min, PH value is 6, the mordant dosage is 3%.

In direct dyeing and pre-mordanting, the dyeing temperature of the dye liquid has the greatest effect on the dyeing rate and fixation rate. In pre-mordanting and post-mordanting, the temperature and dosage of the mordant are both relatively important factors. The deepening effect of pre-mordanting is relatively remarkable. In all, after alum mordanting, the dyeing effect of bamboo fiber is better. The best dyeing temperature corresponding to alum is: 70 °C.

Soaping has certain effect on the dyeing fiber and makes the color of dyeing fiber shallow, while soaping color fastness of bamboo fiber is good and all reaches level 3 or above level 3. The soaping color fastness value can be increased through soaping after mordanting, but the improvement degree of mordant to soaping color fastness is not obvious. However, the color fastness to perspiration of dyeing fiber after dyeing is generally poor, which requires improvement. The mordant is not very helpful in improving the color fastness to perspiration.

All the breaking strength of bamboo fiber increase after dyeing by coptis chinensis, especially the breaking strength of bamboo fiber after mordanting is stronger than that after direct dyeing. However, the breaking elongation of bamboo fiber after dyeing decreases accordingly, the reason may be that the mechanical property structure of bamboo fiber is destroyed after dyeing, resulting in the decrease of breaking elongation.

Acknowledgments

Supported by a project grant from Central Government Funds: “Clothing apparel industrial design center of Fujian Province”

The Academician Workstation for Textile Research Institute of Minjiang University (No.3140420402).

Reference

Kalla S., Marcoux H., De Champlain A., 2015, CFD approach for modeling high and low combustion in a natural draft residential wood log stove, International Journal of Heat and Technology, 33(1), 33-38, DOI: 10.18280/ijht.330105

Lee Y.H., Lee S.G., Hwang E.K., Baek Y.M., Cho S., Kim H.D., 2017, Dyeing properties and deodorizing/antibacterial performance of cotton/silk/wool fabrics dyed with myrrh (Commiphora myrrha) extract. Textile Research Journal, 87(8), 973-983, DOI: 10.3390/ma2010010Lee

Park Y.M., Choi J.H., 2013, Fungi-rice bran based Fermentation of Coptis Chinensis and Curcuma Longa Root and its Influence of Silk Dyeing. Journal of the Korean Society for Clothing Industry, 15(4), 635-641, DOI: 10.5805/SFTI.2013.15.4.635

Rico-Ramirez V., Napoles-Rivera F., Gonzalez-Alatorre G., Diwekar U., 2010, Stochastic optimal control for the treatment of a pathogenic disease, Chemical Engineering Transactions, 21, 217-222, DOI: 10.3303/CET11226001

Sivakumar A., Alagumurthi N., Senthilvelan T., 2015, Experimental and numerical investigation of forced convective heat transfer coefficient in nanofluids of Al2O3/water and CuO/EG in a serpentine shaped microchannel heat sink, International Journal of Heat and Technology, 33(1), 155-160. DOI: 10.18280/ijht.330121