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Development of Protocol for Computerized XRF-ED Zari Testing Using Artificial Intelligence Technique

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ABSTRACT

The fine gold and silver zari thread is an integral part of the silk handloom weaving predominantly practiced in the southern part of the Indian peninsula. The zari thread consists of a silk core, wrapped with flattened silver-copper alloy wire and electroplated with gold. In a brocade silk saree, a minimum of 240 g (1 Marc) of zari is used along with 540 g of dyed silk to produce a silk saree of 6 m in length. The cost of zari is up to 60% of the price of the raw material needed to produce the saree. Earlier, the silver purity of zari thread was assessed using the volumetric analysis technique. Recently, due to the sharp rise in the price of precious metals, the gravimetric technique, which is more time-consuming, has been adopted to test all the zari ingredients as a content percentage to help the fair-trade practice of zari thread. The advent of the computerized XRF-ED technique has accelerated the process of estimating the metal purity values instantly. It could not be used as a tool to estimate the cost of the zari thread as it is traded based on the concentration of silk. Thus, this research aimed to develop the computerized XRF-ED zari testing protocol using the artificial intelligence technique to assess the zari content values. The research findings revealed that the results of the zari thread constituents as content percentage estimated using AI technique are comparable and at par with the test results of the gravimetric analysis. Thus, the XRF-ED testing can be popularized in the field to assess the quality of zari used in the handloom silk saree available to consumers. Findings could also benefit the overall development of the handloom industry faced with tough competition from the silk saree woven with zari imitation thread.

KEYWORDS

zari, metal purity, volumetric method, gravimetric method, XRF-ED, artificial intelligence

INTRODUCTION

Presently, mulberry silk is produced in India in the quantity of 23000 t, of which 15000 t (or 2/3 of the total) are utilized to make silk sarees, primarily on handlooms [1]. The famous silk weaving clusters of Kanchipuram, Arni, and Kumbakonam in the Tamil Nadu province of India once wove silk sarees on handlooms using only fine gold and silver zari thread. A silk saree measuring 6 meters in length was made with a minimum of 240 g (1 marc in the local jargon) of zari and 540 g of dyed silk [2]. The zari thread consists of a pure silk core, wrapped with flattened silver-copper alloy wire and electroplated with gold as shown in Figure 1.

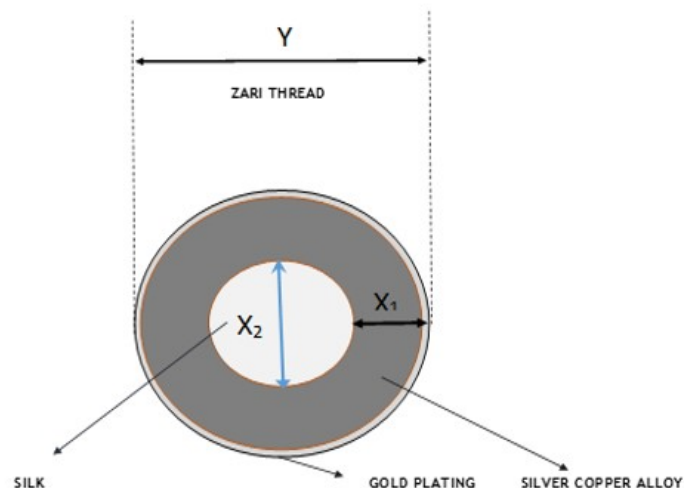


Figure 1. Schematic representation of zari thread

$$Y = X_1 + X_2 \quad (1)$$

Where Y is zari weight, X_1 is metal weight, X_2 is silk weight

$$X_1 = X_i + X_j + X_k \quad (2)$$

Where X_1 is metal weight, X_i is silver weight, X_j is copper weight, X_k is gold weight

During the 1970s, only a few hundred kg of zari were used in handlooms, while silver and silk were about the same in price. Since there was no established zari testing, the quality of zari in terms of its constituent metals was consistent, and the manufacturers, who were primarily from Surat, Gujarat, were regularly supplying the master weavers and other organizations based on mutual trust. The standard was the silver purity or touch in local parlance. The silver purity indicated the percentage of silver in the silver-copper alloy wire necessary for producing zari. Only a goldsmith could verify the purity. The method employed to certify its accuracy was unknown. There was no mention of the zari silk content because there was little price difference between silk and silver.

In the 2000s, the Tamil Nadu region of India utilized over 10 t (40000 marc) of zari thread per month to make silk sarees. All 25 co-operative organizations operating under the auspices of the Tamil Nadu Handloom Department used fine zari to produce silk saree. High-quality zari was also employed by government organizations including the Tamil Nadu Khadi Board, Sarvodaya Sangha, and Khadi Village Industries Commission. The fine gold and silver zari was also used by the private master weavers of Tamil Nadu. Since its beginning, Karnataka Silk Industries Corporation has produced crepe sarees

utilizing only fine zari thread. Moreover, the zari was exchanged or sold by weight. One marc is equal to 240 g of zari which contains 60 g of silk or 25% of the total weight. Due to the growth in the price of precious metals, it was hard to trade zari thread based solely on the purity of the metal. Because of that, master weavers and other government organizations began employing chemical zari testing (gravimetric method), in which 6 g of zari thread is tested using BIS method 9925:1981 as illustrated in Figure 2 representing composition in terms of percentages [3].

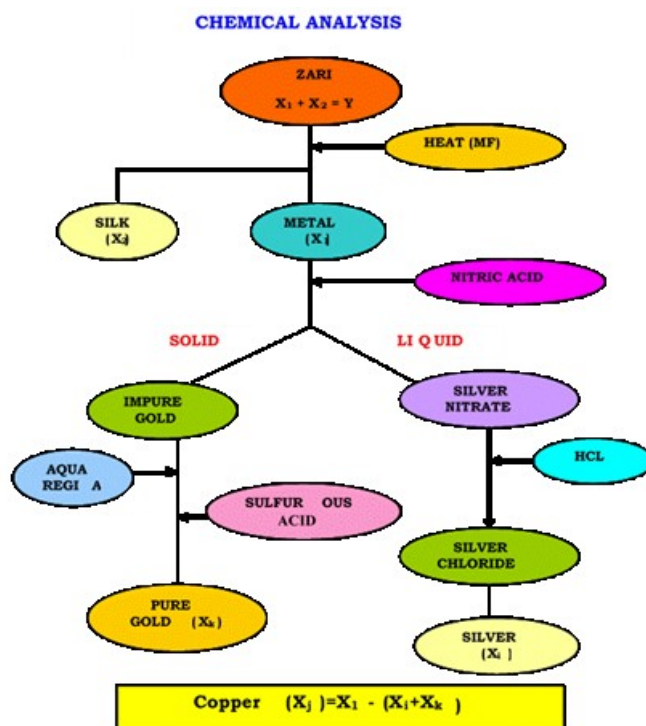


Figure 2. Gravimetric analysis of zari thread

Procedure A (Gravimetric analysis)

It calculates silver, copper, gold and silk content in terms of total weight of zari thread (Y) in percentage. Thus it is following:

$$Z_1 = \frac{X_i}{Y} \quad \text{implies silver content} \quad (3)$$

$$Z_2 = \frac{X_j}{Y} \quad \text{implies copper content} \quad (4)$$

$$Z_3 = \frac{X_k}{Y} \quad \text{implies gold content} \quad (5)$$

$$Z_4 = \frac{X_2}{Y} \quad \text{implies silk content} \quad (6)$$

ZARI MANUFACTURING, PHYSICAL COMPOSITION AND NON-DESTRUCTIVE TESTING

The manufacturers at Surat take care of the silver-copper alloy constituents by meticulously planning the process involved in melting the silver and copper metal in a furnace besides the gold plating techniques. The details about the quantity of silk used for the production of zari are not known to them. Also, the denier of the silk thread, very fine raw silk, plied, twisted, degummed, dyed and used for the production of zari thread is not cross-checked. Moreover, the process of winding the zari thread on the bobbin is controlled by the weight of the zari thread but not by its length. Thus, the bobbin that can hold 60 g of zari thread may have 4600 to 5000 m of zari thread depending on the type of silk used for the production of zari. The length of the zari thread should be 4800 m as per the calculation. The manufacturer would be incurring losses if he supplies 5000 m length of zari thread per bobbin and would be making a profit if he supplies 4600 m of zari thread per bobbin for a given silver-copper alloy. Thus, efforts were made to educate the zari manufacturers to have stringent process and quality control measures in place and the master weavers were asked to purchase the zari thread based on zari content values instead of silver metal purity value (touch). Now, in the silk industry, the zari is transacted on its content value instead of silver purity value. The government of Tamil Nadu made it mandatory to transact the zari thread only on a content basis.

Since it takes two days for a chemical zari test to finish the gravimetric analysis of a zari sample, the Central Silk Board (CSB), a statutory body established in 1948 by an Act of Parliament and operating under the administrative supervision of the Ministry of Textiles, Government of India, introduced computerized zari testing at Kanchipuram in 2007 that adheres to DIN 50987 and ISO 3497 standards and operates on the XRF-ED principle as depicted in Figure 3 [4-6]. After initial calibration with 24-carat gold and 99.99% silver standards provided with the instrument, the computerized zari testing machine, supplied with in-built software, estimates the gold, silver, and copper content of the metal sheath of the zari and by default. The copper content is also estimated.

The software can be programmed for different substrates, such as zari in a saree or bobbin, with various available modules. Calibration must be done by feeding the chemical analysis data of known zari thread and taking into account the entire range of zari thread that is produced and supplied. Earlier, 70% silver (92% touch) to 40% silver (52% touch) zari threads with 0.4 to 0.65% gold content were offered in the market. The zari testing machine was therefore calibrated with 50 different chemical test results, and whenever a zari sample of a different quality was discovered during chemical testing or encountered on the market, the chemical test results were immediately fed to the computerized zari testing machine as purity value by scanning the new sample [7-8].

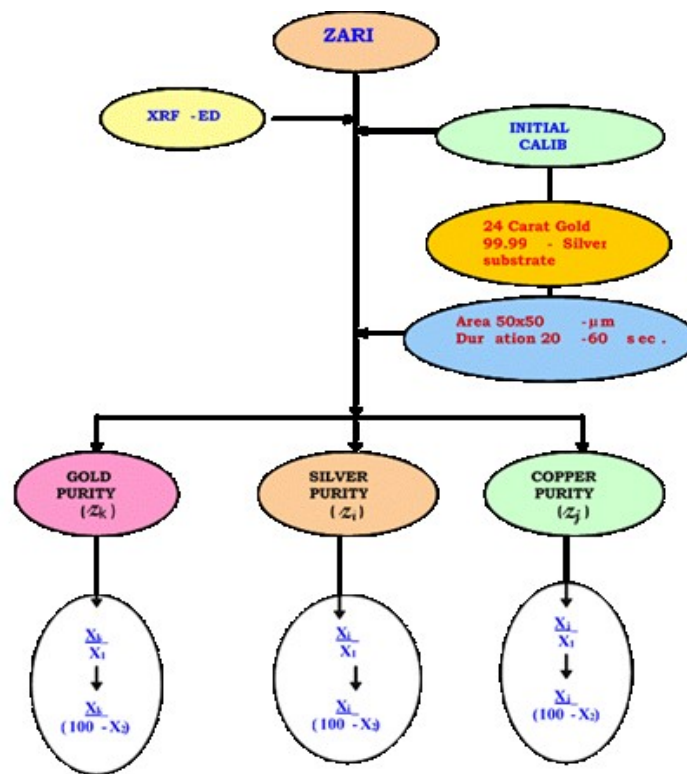


Figure 3. Computerized XRF-ED testing

Procedure B (XRF-ED)

It calculates silver, copper, gold and silk content in terms of total weight of metal (X_1) in percentage (touch in local parlance). Thus it is following:

$$Z_1 = \frac{X_i}{X_1} \quad \text{implies silver content in metal or silver purity} \quad (7)$$

$$Z_2 = \frac{X_j}{X_1} \quad \text{implies copper content in metal or copper purity} \quad (8)$$

$$Z_3 = \frac{X_k}{X_1} \quad \text{implies gold content in metal or gold purity} \quad (9)$$

As a result, the zari content values from chemical analysis data that are currently accessible must be transformed into metal purity values. These metal purity values must be input into the zari apparatus during calibration to build the database while scanning the known sample. The manufacturer-created gold foil library and the silver-copper alloy are used by the system to estimate the metal purity value of the known sample. During calibration, the system asks the user to input the metal purity value based on the chemical analysis. The system software develops a regression equation based on the metal purity values of chemical testing methods and computerized zari testing, arriving at the likely metal purity values of the zari thread, namely silver and copper.

If the zari weight is Y g which contains X_1 g of metal and X_2 g of silk, then X_1 g of metal contains X_i g of silver, X_j g of copper and X_k g of gold. Thus, $X_1 = X_i + X_j + X_k$. The purity of the metals has to be calculated using the formulae $Z_1 = [X_i/X_1]$, $Z_2 = [X_j/X_1]$, $Z_3 = [X_k/X_1]$ and the content value of the constituents has to be calculated using the formula $Z_1 = [X_i/Y]$, $Z_2 = [X_j/Y]$, $Z_3 = [X_k/Y]$. Thus, by combining the above formulae, we can rewrite $Z_1 = Z_1 [1-(X_2/Y)]$, $Z_2 = Z_2 [1-(X_2/Y)]$, $Z_3 = Z_3 [1-(X_2/Y)]$ as explained below. Thus, by using the aforesaid formulae the chemical test results, zari content values are converted to metal purity values and are fed to the computerized zari testing machine during the calibration while developing the application for a particular substrate module viz. Bobbin and saree. In the same way, the metal purity values estimated by the computerized zari testing machine are converted back by assuming the X_2 value which is nothing but the silk content.

Conversion of computerized zari testing metal purity values to zari content value

In order to calculate/estimate Z_n values from Z_n values, where $n=i, j, k$ it is following:

$$Z_1 = \frac{X_i}{X_1} \text{ gives silver content in metal (\%)} \rightarrow X_i = (Z_1)(X_1) \quad (10)$$

$$Z_1 = \frac{X_i}{Y} \text{ gives silver content in zari (\%)} \rightarrow Z_1 = \frac{(Z_1)(X_1)}{Y} = \frac{(Z_1)(Y-X_2)}{Y} \quad (11)$$

Dividing by Y or simplifying it is following

$$Z_1 = (Z_1) \left[1 - \frac{X_2}{Y} \right] \quad (12)$$

Similarly,

$$Z_2 = (Z_2) \left[1 - \frac{X_2}{Y} \right] \quad (13)$$

$$Z_3 = (Z_3) \left[1 - \frac{X_2}{Y} \right] \quad (14)$$

Nowadays, the zari manufacturers have resorted to using metal alloy with 25% to 85% silver purity besides using 0.1 to 0.2% gold. Thus, efforts are required to be made in assuming the X_2 value while converting the metal purity values as zari content values as the complete industry has started the zari trade practices using zari content values. Efforts should be made to educate the zari manufacturer in using consistent quality zari to get the chemical testing results and computerized zari test results are about equal to the required length of zari per bobbin that weighs around 60.5 g. Thus, the use of artificial intelligence is envisaged in estimating the silk content value.

Accordingly, the complete database of the chemical testing (gravimetric method) has to be created for the wide range of zari available in the market, calibrate the computerized zari testing equipment

with the chemical analysis data, fine-tuning the regression analysis to get the best fit, reproduce the chemical analysis results from the computerized zari testing analysis test results which is the metal purity value to the zari content value by assuming the silk content value estimated using AI. Thus, it was envisaged to initiate a research project to develop the protocol for computerized zari testing and validate the same in consultation with the industry partners, besides grading zari based on its content values into different grades.

EXPERIMENTAL

Objective

The main objective of the research is to study the characteristics of commercial zari threads in terms of content and purity and to calibrate the computerized zari testing machine with data from gravimetric analysis. The gravimetric method is destructive and time-consuming (3 days). The proposed computerized zari testing is non-destructive and requires only 5 minutes. It is envisaged to develop the protocol using artificial intelligence (AI) tools to determine the zari content values and validate the findings of zari testing/grading standards for further popularization.

Materials and Methods

68 fine zari thread samples each weighing 15 g were sourced randomly from the private master weavers at Arni and Kanchipuram silk clusters of Tamil Nadu province, zari thread traders at Kanchipuram, and zari manufacturers at Surat, Gujarat province. Each sample was divided into three parts weighing 5 g each. The first part was subjected to gravimetric analysis as per BIS standard test method. The second part was subjected to computerized zari testing analysis as per DIN standard test method with the Fischerscope, XRAY XAN 250, set at 50 kV and 1000 μ A, using Ni as a primary filter with a thickness of 10 μ m, for 60 s in the air available at Kanchipuram and Bangalore. The third part was subjected to volumetric analysis as per BIS standard test method to cross-verify the purity values. The remnant zari thread of the third part was kept as standard for verification at a later stage if required. The test results were compared after converting the metal purity values as per the procedure discussed earlier and statistical analysis was carried out with Minitab 18 software.

To ascertain the randomness of the sample drawn, the chi-square goodness of fit for all the four parameters viz. silk, gold, silver and other metal content was carried out [9]. To improve the data information apropos the normality (goodness of fit), the following analysis was carried out:

1. Outlier Test using Minitab 18 statistical analysis tool –Grubbs Test.
2. Data transformation using the Box-cox method
3. Central Limit theorem using Python programming

To improve the consistency and repeatability in testing, the two types of computerized zari testing equipment were calibrated with gravimetric data and the results after the calibration was statistically analyzed.

To convert the metal purity values found through the computerized zari testing method to the zari content values of the metal, the silk content (X_2) had to be estimated. Since the silk content values were continuous, the regression model and K-Nearest Neighbor (KNN) algorithm were used to estimate the silk content value [10]. The gravimetric data was utilised to generate five grades for gold and silver and five categories for silk using the empirical formula of the normal distribution curve based on the probability distribution. The obtained grading and categorization were discussed with the master weavers through interaction programs. All the zari threads test reports both gravimetric and computerized testing were provided to the master weavers who have given the zari thread samples for this research project free of cost. The first program was conducted at the Arni silk weaving cluster in Tamil Nadu in March 2022 which 81 master weavers attended along with other government agencies. The second program was conducted at Kanchipuram in Tamil Nadu in April 2022 which 54 master weavers attended along with other government agencies. The participants were told about the quality of the zari thread used by the weavers and the importance of introducing computerized zari testing which is fast and non-destructive testing. The grading methodology was modified, based on the feedback, and incorporated into the proposed testing and grading method for the computerized zari testing.

RESULTS AND DISCUSSION

Characteristics of commercial zari threads

The descriptive statistics of all four parameters/constituents of zari samples tested as per the gravimetric analysis are given in Table 1.

The silk content in zari varies from 17 to 25%. Thus, it can be inferred that the zari samples having less silk content shall have more metal (silver-copper alloy) content for a given unit weight of zari thread that should fetch a better price when compared to the zari thread sample having more silk content.

Table 1. Descriptive statistics of the zari samples

N = 68	Silk	Gold	Silver	Others
Minimum	16.96	0.04	12.80	4.34
Maximum	25.18	0.58	70.07	67.35
Mean	20.38	0.22	26.37	53.04
SD	1.78	0.12	9.39	10.32

Normality

The chi-square goodness of fit test was carried out for all four constituents of the zari thread samples that were tested as per the gravimetric analysis.

Silk Content

The chi-square value and the probability distribution curve on the expected and observed frequency are given in Figure 4. It is evident from the chi-square value that the silk content of the zari thread samples tested is not significant as the calculated p-value is 0.666 which is more than 0.01 (significant at 99%) and the observed frequency forms the normal distribution curve.

SAMPLE SIZE =	68					
MINIMUM =	16,96					
MAXIMUM =	25,18					
RANGE	8,22					
CELL LENGTH	1,16			RANGE/(1+3.322* LOG N)		
NUMBER OF CELL	7,09		7	RANGE/CELL LENGTH		
COORECTED CELL LENGTH	1,17					
MEAN =	20,38					
STANDARD DEVIATION=	1,78					
						CHI SQUARE
CELL NUMBER	CELL START	CELL END	PROBABILITY	EXP [E]	OBS [O]	(E-O)^2/E
1st CELL	16,96	18,13	0,0762	5	7	0,638
2nd CELL	18,13	19,31	0,1704	12	12	0,015
3rd CELL	19,31	20,48	0,2500	17	22	1,471
4th CELL	20,48	21,66	0,2407	16	12	1,164
5th CELL	21,66	22,83	0,1520	10	9	0,173
6th CELL	22,83	24,01	0,0630	4	4	0,019
7th CELL	24,01	25,18	0,0171	1	2	0,601
			0,9694	65,9159	68,0000	4,0809
					DF (#CELL-1)	6
					P VALUE =	0,666

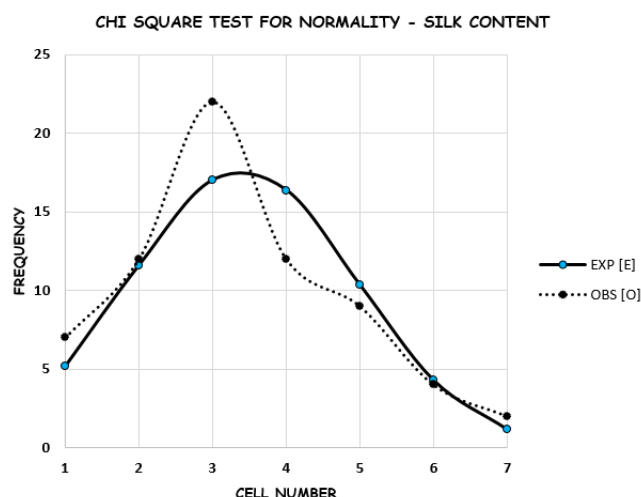


Figure 4. Chi-square normality test of silk content in zari thread

Gold Content

The chi-square value and the probability distribution curve on the expected and observed frequency are given in Figure 5. It is evident from the chi-square value that the gold content of the zari thread samples is not significant as the calculated p-value is 0.015, which is more than 0.01, and the observed frequency forms the normal distribution curve.

SAMPLE SIZE =	68					
MINIMUM =	0,04					
MAXIMUM =	0,58					
RANGE	0,54					
CELL LENGTH	0,08					
NUMBER OF CELL	7,09	7	RANGE/(1+3.322* LOG N)			
COORECTED CELL LENGTH	0,08		RANGE/CELL LENGTH			
MEAN =	0,22					
STANDARD DEVIATION=	0,11					
						CHI SQUARE
CELL NUMBER	CELL START	CELL END	PROBABILITY	EXP [E]	OBS [O]	(E-O)^2/E
1st CELL	0,04	0,12	0,1231	8	11	0,826
2nd CELL	0,12	0,19	0,2304	16	16	0,007
3rd CELL	0,19	0,27	0,2707	18	23	1,145
4th CELL	0,27	0,35	0,1997	14	12	0,184
5th CELL	0,35	0,43	0,0925	6	1	4,450
6th CELL	0,43	0,50	0,0269	2	3	0,752
7th CELL	0,50	0,58	0,0049	0	2	8,352
			0,9482	64,4792	68,0000	15,7166
					DF (#CELL-1)	6
					P VALUE =	0,015

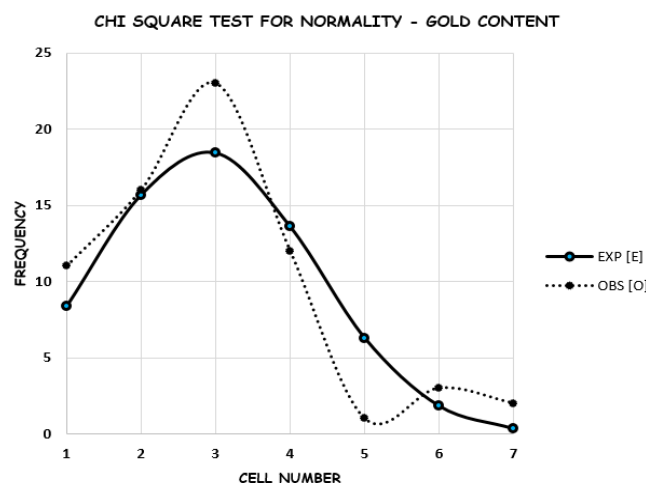


Figure 5 Chi-square normality test of gold content in zari thread

Silver Content

The chi-square value and the probability distribution curve on the expected and observed frequency are given in Figure 6. It is evident from the chi-square value that the silver content of the zari thread sample tested is significant as the calculated p-value is less than 0.05 and the observed frequency does not form the normal distribution curve.

SAMPLE SIZE =	68					
MINIMUM =	12,80					
MAXIMUM =	70,07					
RANGE	57,27					
CELL LENGTH	8,08		RANGE/((1+3.322* LOG N)			
NUMBER OF CELL	7,09	7	RANGE/CELL LENGTH			
COORECTED CELL LENGTH	8,18					
MEAN =	26,37					
STANDARD DEVIATION=	9,39					
						CHI SQUARE
CELL NUMBER	CELL START	CELL END	PROBABILITY	EXP [E]	OBS [O]	(E-O)^2/E
1st CELL	12,80	20,98	0,2089	14	9	1,906
2nd CELL	20,98	29,16	0,3338	23	47	26,012
3rd CELL	29,16	37,34	0,2617	18	4	10,697
4th CELL	37,34	45,53	0,1006	7	6	0,103
5th CELL	45,53	53,71	0,0189	1	0	1,284
6th CELL	53,71	61,89	0,0017	0	0	0,117
7th CELL	61,89	70,07	0,0001	0	2	767,845
			0,9257	62,9476	68,0000	807,9646
					DF (#CELL-1)	6
					P VALUE =	0,000

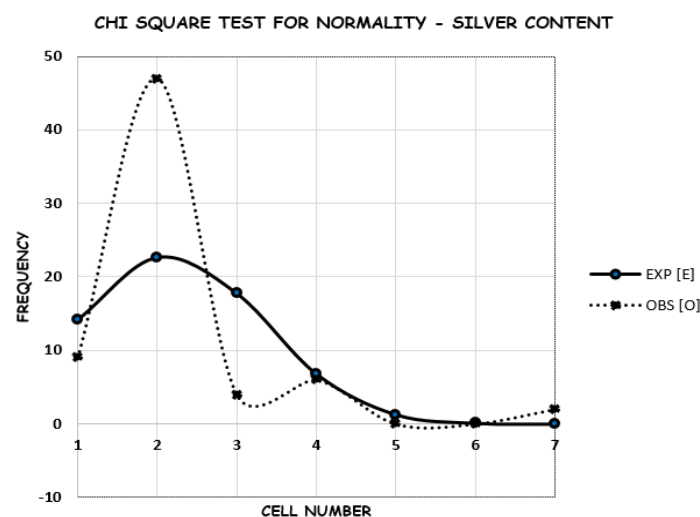


Figure 6. Chi-square normality test of silver content in zari thread

Thus, it can be inferred that only silk and gold content in the zari thread form the normal distribution curve whereas silver in the zari thread did not form the normal distribution curve and hence require more samples. Silver and copper are interrelated as the outer sheath of the zari is in silver-copper alloy.

Outlier Test

The outlier test (Grubbs test) in respect of the gold and silver content was carried out. The silver content showed that two sample values are outliers as shown in Figure 7. In reality, the silver content quality zari threads are manufactured and used by reputable master weavers, therefore the outlier results are not due to sampling mistake.

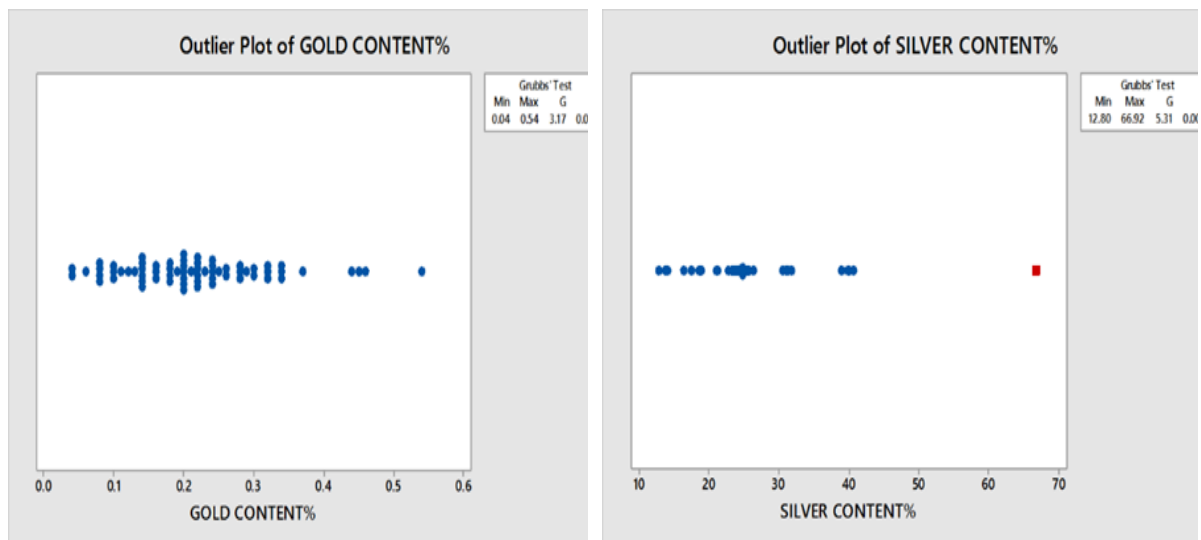


Figure 7. Chi-square normality test of silver content in zari thread

Data transformation

The lambda (λ) value assumed for the data transformation as per the Box-Cox method is given in Table 2. The p-value of the chi-square test in respect of gold content improves considerably as high as 0.89 when $\lambda = 0.5$ as shown in Figure 8. In the same way, the p-value of the chi-square test for silver content didn't improve when $\lambda = -1.0$ as shown in Figure 9 but the bell shape curve in normality in the goodness of fit is almost equivalent to the normal distribution curve.

Table 2. Data transformation; Box-cox method

Lambda λ	Standard transformation
- 3	Inverse cube
- 2	Inverse square
- 1	Inverse
- 0.5	Inverse square root
0	Logarithmic
0.5	Square root
1	No transformation
2	Square
3	Cube

SAMPLE SIZE =	68					
MINIMUM =	0,20					
MAXIMUM =	0,76					
RANGE	0,56					
CELL LENGTH	0,08					RANGE/(1+3.322* LOG N)
NUMBER OF CELL	7,09					7 RANGE/CELL LENGTH
COORECTED CELL LENGTH	0,08					
MEAN =	0,46					
STANDARD DEVIATION=	0,12					
						CHI SQUARE
CELL NUMBER	CELL START	CELL END	PROBABILI LITY	EXP [E]	OBS [O]	(E-O)^2/E
1st CELL	0,20	0,28	0,0525	4	3	0,092
2nd CELL	0,28	0,36	0,1411	10	9	0,037
3rd CELL	0,36	0,44	0,2412	16	15	0,120
4th CELL	0,44	0,52	0,2623	18	23	1,494
5th CELL	0,52	0,60	0,1815	12	12	0,010
6th CELL	0,60	0,68	0,0799	5	4	0,379
7th CELL	0,68	0,76	0,0224	2	2	0,151
			0,9811	66,712	68,000	2,2821
					DF (#CELL-1)	6
					P VALUE =	0,892

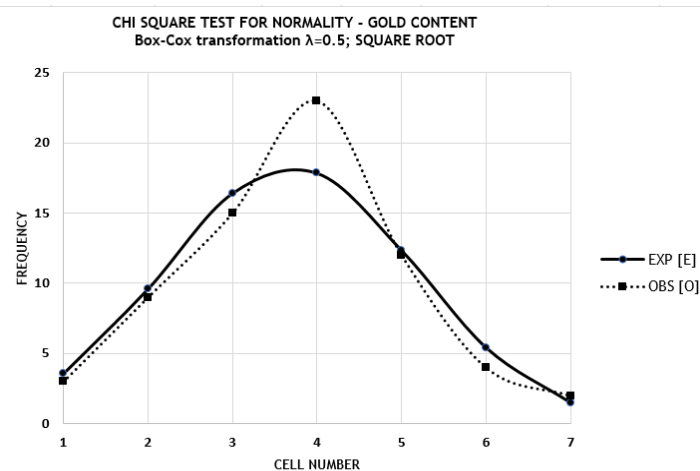


Figure 8. Chi-square normality test of gold content in zari thread; Box-Cox data transformation with $\lambda = 0.5$ (Square root)

SAMPLE SIZE =	68					
MINIMUM =	0,0143					
MAXIMUM =	0,0781					
RANGE	0,0639					
CELL LENGTH	0,0090					RANGE/(1+3.322* LOG N)
NUMBER OF CELL	7,0876					7 RANGE/CELL LENGTH
COORECTED CELL LENGTH	0,0091					
MEAN =	0,0412					
STANDARD DEVIATION=	0,0109					
						CHI SQUARE
CELL NUMBER	CELL START	CELL END	PROBABILI LITY	EXP [E]	OBS [O]	(E-O)^2/E
1st CELL	0,0143	0,0234	0,0449	3	2	0,361
2nd CELL	0,0234	0,0325	0,1623	11	9	0,377
3rd CELL	0,0325	0,0416	0,3033	21	32	6,271
4th CELL	0,0416	0,0508	0,2931	20	16	0,775
5th CELL	0,0508	0,0599	0,1464	10	5	2,468
6th CELL	0,0599	0,0690	0,0378	3	1	0,957
7th CELL	0,0690	0,0781	0,0050	0	3	20,769
			0,9928	67,510	68,000	31,9776
					DF (#CELL-1)	6
					P VALUE =	0,000

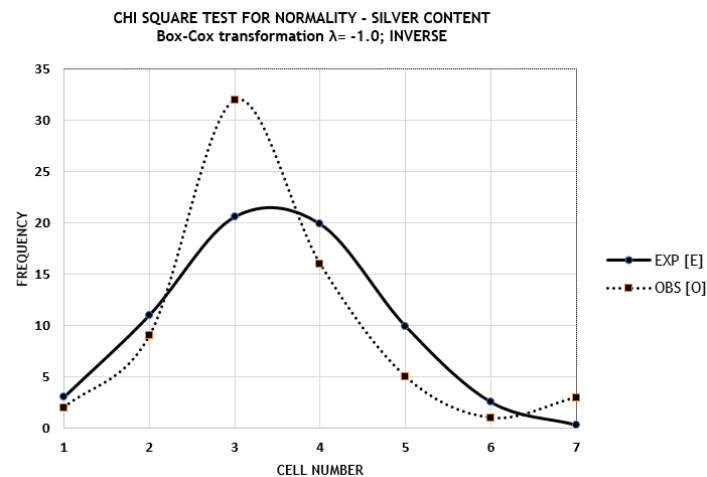


Figure 9. Chi-square normality test of silver content in zari thread; Box-Cox data transformation with $\lambda = -1.0$ (Inverse)

Central limit theorem

The silver content data with and without outlier values were analyzed based on central limit theorem using Python software (Figure 10). The silver content values in the range 42-64% in the case of “with outlier” values and silver content values in the range 27.5-31% in the case of “without outlier” values are missing and the said range samples need to be collected and tested to get the insignificant p-value of chi-square test in the goodness of fit.

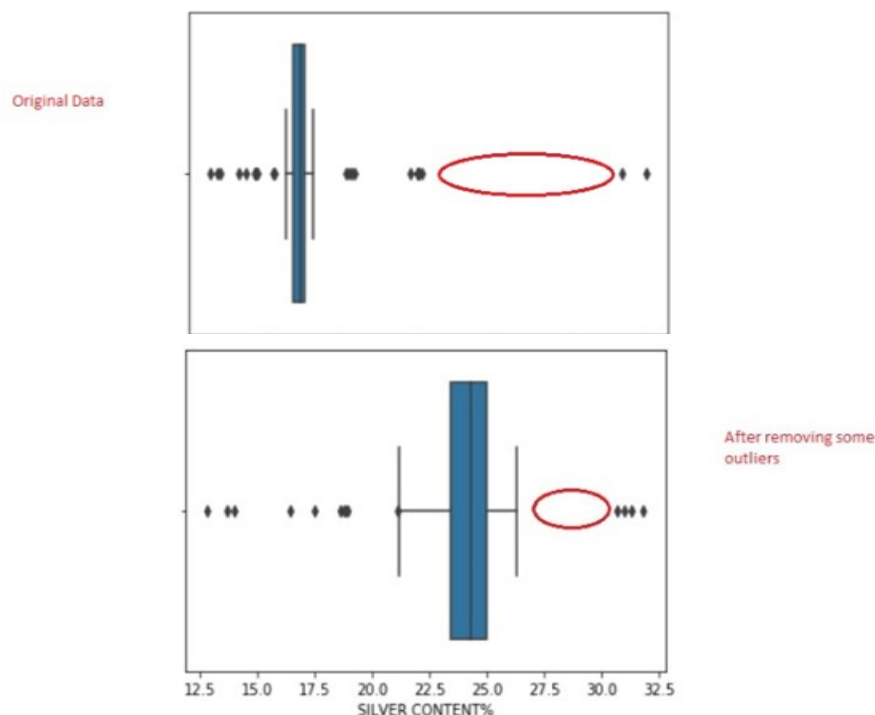


Figure 10. Chi-square normality test of silver content in zari thread; central limit theorem with and without outliers.

Based on the findings of the central limit theorem, which states that as the sample size increases, the distribution of a sample variable approximates a normal distribution (i.e., a "bell curve"), assuming that all samples are identical in size and regardless of the population's actual distribution shape. In order to make the silver content represent the population that follows the normal distribution, it is agreed to obtain 15 more samples from the producers. Meanwhile, the algorithm used in artificial intelligence doesn't require the data to form a particular distribution, it is decided to explore other objectives of the research study.

Calibration of computerized zari testing equipment

The gravimetric data available in respect of 68 samples was utilized to calibrate the computerized zari testing machine. The statistical analysis of metal purity values before and after the calibration in respect of two types of equipment that are considered under this research project are given in Table 3. The results after calibration have improved greatly and are nearly identical to the gravimetric analysis since the p-value of the paired t-test is not significant, indicating that the results obtained in computerized zari testing analysis are comparable to the gravimetric analysis. The correlation coefficient is also very significant for all three parameters. The collimator size in respect of a particular type of computerized zari testing equipment has influenced the test parameter, which is shown in the table. Thus, both the computerized zari testing machines are now able to test the zari samples for their metal purity values with higher precision that are comparable with gravimetric analysis converted metal purity values.

Table 3. Statistical analysis before and after calibration

XRF-ED Instrument	Kanchipuram			Bangalore		
Parameter	Gold	Silver	Copper	Gold	Silver	Copper
A. Before calibration						
Correlation; r-value	0.13	0.79	0.84	0.18	0.69	0.74
Paired t-test; p-value	0.00	0.00	0.00	0.00	0.00	0.00
B. After calibration						
I. 0.3 mm Collimator						
Correlation; r-value	0.84	0.99	0.99	0.80	0.97	0.97
Paired t-test; p-value	0.08	0.07	0.07	0.08	0.06	0.06
II. 0.1 mm Collimator						
Correlation; r-value	0.74	0.98	0.98			
Paired t-test; p-value	0.12	0.10	0.10			

Note: 1. In Correlation, if an r value >0.75 is acceptable and >0.9 is desirable

2. In paired t-test, if p-value >0.01 is acceptable and >0.05 is desirable

Estimation of silk content

The gravimetric data of 68 samples on the zari content values viz. Z_1 , Z_2 , and Z_3 were converted to metal purity values viz. Z_1 , Z_2 , Z_3 . All 68 samples were tested for metal purity values in computerized zari testing equipment. The gravimetric metal purity converted data Z_1 , Z_2 , Z_3 and silk content Z_4 along with the metal purity values measured using the computerized zari testing equipment were analyzed based on the KNN algorithm using the python programming. The silk content value was calculated for all the samples. The actual and estimated values of all the samples are given in Table 4 along with the p-value of the paired t-test as well as the correlation coefficient r-value.

Table 4. Statistical analysis predicted by KNN algorithm versus actual gravimetric value

Parameter	Silk %	Gold %	Silver %	Copper %
Correlation; r-value	0.46	0.80	0.99	0.99
Paired t-test; p-value	0.07	0.07	0.34	0.23

Note: 1. In Correlation, if r-value >0.75 is acceptable and >0.9 is desirable

2. In paired t-test, if p-value >0.01 is acceptable and >0.05 is desirable

It is evident that the correlation coefficient for all four parameters, actual vs estimated, is significant and the p-value of the paired t-test is more than 0.05 which is highly desirable. Thus, it can be inferred that the KNN algorithm estimates the silk content of the zari thread, which is almost equal to the gravimetric value. Hence, it is concluded that based on computerized zari testing values, the KNN algorithm can estimate the silk content very precisely which is essential to estimate the other metal content of zari thread for fair trade practice.

Grading of zari thread

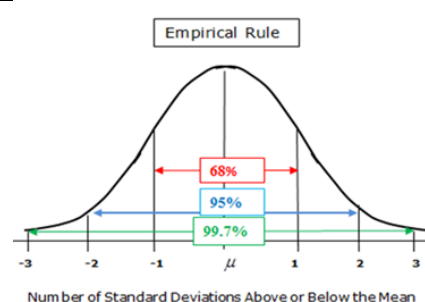
Initial Grading

The important three constituents of the zari thread viz. gold, silver and silk are only considered for zari thread grading as per the empirical formula of the normal distribution as shown in Figure 11. Thus, the mean and standard deviation of the said three parameters were used to obtain the grades for gold and silver and the category for silk content. The gold and silver content data of the zari thread generated in the gravimetric analysis have been segregated into five grades, A to E and silk content data have been divided into five categories I to V as shown in the figure.

Figure 11. Initial grading of zari thread based on gold, silver and silk content in percentage (%)

	#	Silk	Gold	Silver	Others
N = 68	Max	25.18	0.58	70.07	67.35
	Min	16.96	0.04	12.80	4.34
	Ave	20.38	0.22	26.37	53.04
	SD	1.78	0.11	9.39	10.32
68%	1	22.15	0.33	35.76	63.35
	-1	18.60	0.11	16.98	42.72
95%	1.96	23.86	0.44	44.78	73.26
	-1.96	16.89	0.00	7.96	32.81
99%	2.58	24.96	0.507	50.60	79.66
	-2.58	15.79	-0.06	2.13	26.41

Grade/ Category	Gold %	Silver %	Silk %
A / I	> 0.45	> 46	< 17
B / II	> 0.33 up to 0.45	> 36 up to 46	> 17 up to 19
C / III	> 0.11 up to 0.33	> 18 up to 36	> 19 up to 22
D / IV	> 0.015 up to 0.11	> 8 up to 18	> 22 up to 24
E / V	< = 0.015	< = 8	> = 24



Validation Program

The computerized zari testing protocol along with the grading techniques was discussed with the stakeholders by conducting the validation programs. At two major silk handloom weaving clusters viz. Kanchipuram and Arni in which 135 master weavers and other officials attended the validation program gave their feedback through an online Google sheet. The personal information of the participants, their technical knowledge of zari quality and their opinion on the popularizing the computerized zari testing protocol including its grading was asked. The Google sheet was shared with all the participants who attended the program, and anonymised feedback from 51 participants was collected and compiled. The extract of the feedback is as follows.

- All opined that the computerized zari testing method has to be popularized by installing the equipment in major silk weaving clusters and silk markets in the southern part of India to protect the consumer as well as to get reasonable remunerative prices for the quality of zari used in the silk saree.
- The five grades for gold and silver content and three categories for silk content were suggested.
- It was suggested that the zari having less than 20% silver content and 0.2% gold content should be graded as the lowest grade (E).

- d) It was opined that an alphanumeric grade should be given to the overall grade of the zari thread for its quality and to be popularized through advertisement.

Final Grading

The grading methods have been changed based on the feedback received from the stakeholder in the validation program. The revised grade details are mentioned in Table 5 for all three important constituents of the zari thread along with the percentage of the population it would represent. The overall grade of the zari would be the alphanumeric value with three digits, the first two alphabetic digits would represent gold and silver grades respectively and the third numeric digit would represent the silk category. Thus, the grade for samples A, B and C would be of the grade “BBII”, “BBIII” and “BCIII”.

Table 5. Final grading of zari thread based on gold, silver and silk content

A. Gold %		
Range	Grade	Population %
Above 0.55%	A	0.12
Above 0.44% and up to 0.55%	B	2.15
Above 0.33% and up to 0.44%	C	13.59
0.20% and up to 0.33%	D	41.35
Below 0.20 %	E	42.79
B. Silver		
Above 50%	A	0.50
Above 45% and up to 50%	B	2.00
Above 35% and up to 45%	C	13.36
20% and up to 35%	D	59.26
Below 20%	E	24.88
C. Silk		
Below 20%	I	41.55
20% and up to 22.15%	II	42.45
Above 22.15%	III	16.00

CONCLUSION

The zari samples collected from the stakeholders of the silk industry and analyzed using the gravimetric analysis can be used as standards to calibrate the computerized zari testing machine to get the accurate metal content value. Moreover, the silk content of the zari value can be estimated through an algorithm using python programming. Thus, the computerized zari testing protocol developed in this research enables testing of zari thread in either bobbin or saree form, which is a

non-destructive analysis, to get the content value of the constituent of fine zari thread, used in the production of high-value brocade silk saree. The computerized zari test results are at par with the gravimetric analysis test results. The instrument requires 2-3 minutes to assess the zari thread with the help of the KNN algorithm using the artificial intelligence technique.

The findings in unequivocal terms recommend the popularization of computerized zari testing and grading to protect the interest of the manufacturers who use the genuinely high-quality zari thread to weave the silk saree that should fetch a reasonable remunerative price.

Author Contributions

Conceptualization – Katpadi Mohammed AK; methodology – Katpadi Mohammed AK and Kanniyappan R; formal analysis – Katpadi Mohammed AK and Kanniyappan R; investigation – Katpadi Mohammed AK, Kanniyappan R and Shirol MM; resources – Katpadi Mohammed AK and Naik SV; writing-original draft preparation – Katpadi Mohammed AK, Kanniyappan R and Shirol MM; writing-review and editing – Katpadi Mohammed AK, Kanniyappan R and Shirol MM; visualization – Katpadi Mohammed AK and Naik SV; supervision – Naik SV. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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