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SILK COCOONS QUALITY CHARACTERIZATION BY FUZZY CONTROL CHART

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ABSTRACT

This paper deals with the application of fuzzy multinomial control chart (FM-chart) with variable sample size for characterizing the mulberry multi-bivoltine silk cocoons quality and the result is compared with the conventional p-chart. Silk cocoons quality has been classified under various categories such as reject, poor, medium, good and excellent. The FM-chart offers a holistic approach about the quality of silk cocoons by considering the proportions of all categories; however, p-chart only considers the proportion of rejected category of silk cocoons. Consequently, FM-chart can able to monitor the silk cocoon quality characteristic in better way than p-chart.

KEYWORDS: *Cocoons quality, Control limits, Fuzzy Control Chart, FM–chart, P–chart, Silk cocoons.*

1. INTRODUCTION

Sericulture is an agro-based industry. It involves rearing of silkworms for the production of raw silk, which is the yarn obtained out of cocoons spun by certain species of insects. Unlike other natural fibres, sericulture is a unique combination of botanical, zoological and textile sciences dealing with on and off-farm activities. Hence, handling of silk textiles is a little delicate.

The raw material of silk yarn is cocoon and that of cocoon is the silkworm seed. Silk cocoons being a bio-material have huge intra and inter-cocoon lots variations. The quality of the raw material is a very important role during processing and subsequently has great bearing on the end product as well [1]. The silk cocoons quality plays a major role in reeling and ultimately govern the final product quality. But quality perception in silk sector is still at very budding state. Because of absence of any scientific quality control approach, sometimes no direct correlation between price and quality of cocoons is found. In the backdrop of such affairs, there is an urgent need of sound process control system for silk cocoons quality characterization.

Control chart is regarded as the most frequently applied statistical process control tools [2]. The control chart technique is the most commonly used in industries for quality monitoring. A control chart consists of three horizontal lines, namely upper control limit (UCL), center line (CL) and lower control limit (LCL). The CL in a control chart denotes the average quality of the product. If a point lies within UCL and LCL, then the process is deemed to be under control. Otherwise, a point plotted outside the control limits can be regarded as evidence representing that the process is out of control and, hence preventive or corrective actions are necessary in order to find and eliminate the assignable cause or causes, which subsequently result in improving quality characteristics [3-4].

One of the basic control charts for attributes is the *p*-chart which can also be is used for the samples with varying sizes. It shows a proportion of nonconforming items rather than the actual count for each lot which is classified as either nonconforming or conforming to the specified quality characteristic. Typically, the conformity to specifications on a quality standard is evaluated onto a two-state scales, e.g. acceptable or unacceptable, good or bad and so on. However the binary classification might not be appropriate in case of silk cocoons which may be classified in more than two categories using linguistic variables such as 'poor quality', 'medium quality', 'good quality', and 'excellent quality'. A fuzzy multinomial control chart (FM-chart) is able to deal with the linguistic variables which are classified into more than two categories. In this paper *p*-chart is compared with FM-chart for characterization of silk cocoons quality.

2. THE *P*–CHART

Let w be a sample statistic that measures a quality characteristic, and suppose that the mean of w is μ_w and the standard deviation of w is σ_w. Then the CL, UCL and the LCL for the Shewhart control chart are as follows [5]:

$$\left.\begin{aligned} UCL &= \mu_w + d\sigma_w \\ CL &= \mu_w \\ LCL &= \mu_w - d\sigma_w \end{aligned}\right\} \qquad (1)$$

(1)

Where d is the distance of the control limits from the CL, in multiples of the standard deviation of w. It is customary to use $d = 3$.

The control limits for *p*-chart with variable sample sizes is obtained as follows:

$$\left.\begin{aligned} UCL_i &= \bar{p} + d\sqrt{\frac{\bar{p}(1-\bar{p})}{n_i}} \\ CL &= \bar{p} = \frac{\sum_{i=1}^{k} D_i}{\sum_{i=1}^{k} n_i} \\ LCL_i &= \bar{p} - d\sqrt{\frac{\bar{p}(1-\bar{p})}{n_i}} \end{aligned}\right\} \qquad (2)$$

Where k = number of samples, n_i= number of units in sample i, D_i=number of nonconforming units in sample i, $\bar{p}$ = average fraction of nonconforming, UCL_i =upper control limit of sample i, and LCL_i= lower control limit of sample i.

3. THE FM CHART

The concept of fuzzy logic plays a fundamental role in formulating quantitative fuzzy variables [6-7]. These are variables whose states are fuzzy members. The members represent linguistic concepts, such as good quality, medium quality, bad quality and so on, as interpreted in a particular context [8-9]. In case of p-chart, the conformity to specifications on a quality standard is evaluated onto a two-state scale, for example, acceptable or unacceptable, good or bad, and so on. In some situations this type of binary classification might not be suitable, where product quality can assume more intermediate states. A FM-chart can able tackle the situation when the products are classified into mutually exclusive multinomial linguistic categories. A brief introduction of a FM-chart with variable sample sizes is given in the following lines.

Based upon fuzzy et theory, a linguistic variable L is characterized by the set of k mutually exclusive members $\{l_1,l_2,...l_k\}$. We attach a weight m_i to each term l_i (where $i = 1, 2,\dots k$) that reflects the degree of membership in the set. Then a fuzzy set can be written as $\tilde{L} = \{(l_1,m_1),(l_2,m_2),\dots(l_k,m_k)\}$ Assume that the production process is operating in a stable manner and p_i is the probability that an item is l_i and successive items produced are independent. Suppose that a random sample of size n_i units of the product is selected and let X_i,be the number of items of the product that are l_i. Then $\{X_1, X_2, \dots X_k\}$ has a multinomial distribution with parameters n_i and $p_1,p_2, \dots p_k$. It is known that each X_i marginally has a binomial distribution with the mean $n_i p_i$ and variance $n_i p_i(1-p_i)$ respectively. The weighted average of the linguistic variable $\tilde{L}$ with sample size n_i is defined by [5,10]:

$$\bar{\tilde{L}} = \frac{\sum_{i=1}^{k} X_i m_i}{\sum_{i=1}^{k} X_i} = \frac{\sum_{i=1}^{k} X_i m_i}{n_i}, \quad n_i \in \{n_1, n_2, \dots n_k\} \qquad (3)$$

where $n_1, n_2, \dots n_s$ are pre-determined sample sizes. The control limits for FM-chart are

$$\left.\begin{aligned} UCL &= E[\bar{\tilde{L}}] + d\sqrt{var(\bar{\tilde{L}})} \\ CL &= E[\bar{\tilde{L}}] \\ LCL &= E[\bar{\tilde{L}}] - d\sqrt{var(\bar{\tilde{L}})} \end{aligned}\right\} \qquad (4)$$

The expressions of $E[\bar{\tilde{L}}]$ and $var(\bar{\tilde{L}})$ in Equation (4) can be written as follows:

$$E[\bar{\tilde{L}}] = \sum_{i=1}^{k} p_i m_i \qquad (5)$$

$$var(\bar{\tilde{L}}) = \frac{1}{n_i}\left[\sum_{i=1}^{k} m_i^2 p_i(1-p_i) - 2\sum_{i=1 i<j}^{k}\sum_{j=1}^{k} m_i m_j p_i p_j\right] \qquad (6)$$

By putting the Equations 5-6 in control limits for FM-chart, Equation 4 becomes

$$\left.\begin{aligned} UCL_i &= \sum_{i=1}^{k} p_i m_i + d\sqrt{\frac{1}{n_i}\left[\sum_{i=1}^{k} m_i^2 p_i(1-p_i) - 2\sum_{i=1 i<j}^{k}\sum_{j=1}^{k} m_i m_j p_i p_j\right]} \\ CL &= \sum_{i=1}^{k} p_i m_i \\ LCL_i &= \sum_{i=1}^{k} p_i m_i - d\sqrt{\frac{1}{n_i}\left[\sum_{i=1}^{k} m_i^2 p_i(1-p_i) - 2\sum_{i=1 i<j}^{k}\sum_{j=1}^{k} m_i m_j p_i p_j\right]} \end{aligned}\right\} \qquad (7)$$

4. ASSESSMENT OF SILK COCOONS

Due to colossal heterogeneity in or within a lot of silk cocoon, random sampling with variable sample size seems to be the right approach for assessment of cocoon. In practice, quality of silk cocoons is mostly assessed by some tactual observations. In fact, the assessors have that much of expertise to evaluate the cocoon characteristics with their experience. In the present study, these visual and tactual expertise of some experienced reelers have been utilized during assessment and categorization of silk cocoons. Total 54 lots of multi-bivoltine silk cocoons of variable size sare selected. Table 1 illustrates the linguistic assessments of each lot of silk cocoons in five different categories such as 'Reject', 'Poor Quality', 'Medium Quality', 'Good Quality' and 'Excellent Quality' respectively. In Table 1 the first category 'Reject' means unreelable; 'Poor' means having poor shell compactness, less cocoon weight etc. but otherwise reelable; 'Medium' indicates moderate shell structure, moderate resiliency, higher silk content etc.; 'Good' signifies the cocoon quality which is satisfactorily acceptable to the reelers for a reasonably good output. In fact, in a normally acceptable lot of cocoon, the larger number of cocoons generally falls within this category. Finally, the category 'Excellent' is the mostly desired category that are superior over others in terms of shell weight, cocoon size and shape, color, resiliency, expected output etc. In Table 1 the lot size indicates the total number of cocoons assessed for that particular lot which includes all five categories. For example, lot no. 1 has total 110 number of silk cocoons amongst which 2, 12, 17, 51 and 28 cocoons are categorized as 'Reject', 'Poor Quality', 'Medium Quality', 'Good Quality' and 'Excellent Quality', respectively.

Table 1- Linguistic assessment of silk cocoon quality

Lot No.	Lot Size	Reject	Poor Quality	Medium Quality	Good Quality	Excellent Quality
1	110	2	12	17	51	28
2	115	3	10	14	56	32
3	120	4	13	17	57	29
4	100	12	13	16	40	19

5	110	2	9	15	53	31
6	105	3	12	18	41	31
7	110	4	11	22	52	21
8	120	4	15	23	58	20
9	110	3	16	21	51	19
10	100	2	16	20	41	21
11	110	3	14	21	50	22
12	100	2	11	20	49	18
13	115	4	15	19	54	23
14	100	3	10	18	47	22
15	94	2	10	15	47	20
16	100	2	14	19	42	23
17	122	3	17	20	60	22
18	110	2	11	24	52	21
19	115	3	16	21	59	16
20	100	1	9	17	53	20
21	110	2	13	18	56	21
22	110	3	13	16	48	30
23	115	3	13	19	48	32
24	105	2	12	16	46	29
25	105	2	11	17	55	20
26	110	4	12	14	58	22
27	115	1	12	15	68	19
28	100	12	12	6	52	18
29	110	2	11	13	62	22
30	115	3	16	23	52	21
31	130	5	18	22	62	23
32	120	4	20	21	53	22
33	120	5	21	19	54	21
34	100	13	10	19	35	23
35	110	6	16	24	49	15
36	120	7	26	20	49	18
37	90	6	20	8	44	12
38	105	3	13	21	49	19
39	110	3	13	15	58	21
40	110	3	16	16	55	20
41	120	4	19	18	57	22
42	110	2	12	19	44	33
43	80	10	10	12	29	19
44	80	14	8	8	32	18
45	100	2	12	17	48	21
46	120	3	10	16	56	35
47	115	3	13	17	45	37
48	110	2	8	17	44	39
49	110	3	21	18	46	22
50	100	2	15	20	41	22
51	110	4	15	21	49	21
52	110	3	13	20	54	20
53	120	11	12	23	48	26
54	100	5	25	19	38	13

5. CONSTRUCTION OF *P*-CHART AND FM-CHART FOR SILK COCOONS

To monitor the quality of multi-bivoltine mulberry silk cocoons, 54 lots of different sizes are selected. To construct the *p*-chart for characterization of silk cocoons quality, the fraction of nonconforming cocoons for each lot ($\hat{p}_i$) and the average fraction of nonconforming cocoons($\bar{p}$)are estimated as follows:

$$\hat{p}_i = \frac{D_i}{n_i};\ n_i \in \{n_1, n_2, \dots . n_k\} \quad (8)$$

$$\hat{p}_1 = \frac{2}{110} = 0.01818;\ \hat{p}_2 = \frac{3}{115} = 0.02609;\ \ \hat{p}_3 = \frac{4}{120} = 0.03333; \text{and so on}$$

$$\bar{p} = \frac{\sum_{i=1}^{k} D_i}{\sum_{r=1}^{s} n_i} = \frac{221}{5861} = 0.037707$$

The center line and control limits of *p*-chart are calculated for each lot using Equation (2). Table 2 shows the values of $\hat{p}_i$ and control limits for each lot. Examples of estimating the center line and control limits of *p*-chart for samples 1 and 2 are shown below.

For sample 1:

$$UCL_1 = \bar{p} + d\sqrt{\frac{\bar{p}(1-\bar{p})}{n_r}} = 0.037707 + 3\sqrt{\frac{0.037707(1-0.037707)}{110}} = 0.092193$$

$$CL = \bar{p}_i = \frac{\sum_{i=1}^{k} D_i}{\sum_{r=1}^{s} n_r} = \frac{221}{5861} = 0.037707$$

$$LCL_1 = \bar{p} - d\sqrt{\frac{\bar{p}(1-\bar{p})}{n_r}} = 0.037707 - 3\sqrt{\frac{0.037707(1-0.037707)}{110}} = -0.01678 \equiv 0$$

For sample 2:

$$UCL_1 = \bar{p} + d\sqrt{\frac{\bar{p}(1-\bar{p})}{n_r}} = 0.037707 + 3\sqrt{\frac{0.037707(1-0.037707)}{115}} = 0.090996$$

$$CL_2 = 0.037707$$

$$LCL_2 = \bar{p} - d\sqrt{\frac{\bar{p}(1-\bar{p})}{n_r}} = 0.037707 - 3\sqrt{\frac{0.037707(1-0.037707)}{115}} = -0.01558 \equiv 0$$

The LCL values of defective cocoon proportion are mathematically computed as negatives for each lot. As negative proportion of defective cocoon is not possible, the LCL values are considered to be zeros.

For construction of FM-chart five linguistic variables are considered. The degree of memberships of silk cocoons for each categories are as follows: Reject: 1, Poor quality: 0.75, Medium Quality: 0.50, Good Quality: 0.25, Excellent quality: 0. The center line and control limits of FM-chart are calculated for each lot using Equation (7). Examples of calculating the center line and control limits of FM-chart for the first two lots are shown below.

For sample 1:

$$UCL_1 = \sum_{i=1}^{k} p_i m_i + d\sqrt{\frac{1}{n_1}\left[\sum_{i=1}^{k} m_i^2 p_i(1-p_i) - 2\sum_{i=1 i<j}^{k}\sum_{j=1}^{k} m_i m_j p_i p_j\right]}$$

$$= 0.33032 + 3\sqrt{0.00063614} = 0.40598$$

$$CL = \sum_{i=1}^{k} p_i m_i = 0.33032$$

$$LCL_1 = \sum_{i=1}^{k} p_i m_i - d\sqrt{\frac{1}{n_1}\left[\sum_{i=1}^{k} m_i^2 p_i(1-p_i) - 2\sum_{i=1 i<j}^{k}\sum_{j=1}^{k} m_i m_j p_i p_j\right]}$$

$$= 0.33032 - 3\sqrt{0.00063614} = 0.25465$$

For sample 2:

$$UCL_2 = \sum_{i=1}^{k} p_i m_i + d\sqrt{\frac{1}{n_2}\left[\sum_{i=1}^{k} m_i^2 p_i(1-p_i) - 2\sum_{i=1 i<j}^{k}\sum_{j=1}^{k} m_i m_j p_i p_j\right]}$$

$$= 0.33032 + 3\sqrt{0.00060848} = 0.40432$$

$$CL = \sum_{i=1}^{k} p_i m_i = 0.33032$$

$$LCL_2 = \sum_{i=1}^{k} p_i m_i - d\sqrt{\frac{1}{n_2}\left[\sum_{i=1}^{k} m_i^2 p_i(1-p_i) - 2\sum_{i=1 i<j}^{k}\sum_{j=1}^{k} m_i m_j p_i p_j\right]}$$

$$= 0.33032 - 3\sqrt{0.00060848} = 0.25632$$

Table 2 – Control limits and p_i values for p –chart

Lot No.	UCL	LCL	p_i	Lot No.	UCL	LCL	p_i
1	0.09219	0	0.01818	28	0.09485	0	0.12000
2	0.09100	0	0.02609	29	0.09219	0	0.01818
3	0.08987	0	0.03333	30	0.09100	0	0.02609
4	0.09485	0	0.12000	31	0.08783	0	0.03846
5	0.09219	0	0.01818	32	0.08987	0	0.03333
6	0.09348	0	0.02857	33	0.08987	0	0.04167
7	0.09219	0	0.03636	34	0.09485	0	0.13000
8	0.08987	0	0.03333	35	0.09219	0	0.05455
9	0.09219	0	0.02727	36	0.08987	0	0.05833

10	0.09485	0	0.02000	37	0.09794	0	0.06667
11	0.09219	0	0.02727	38	0.09348	0	0.02857
12	0.09485	0	0.02000	39	0.09219	0	0.02727
13	0.09100	0	0.03478	40	0.09219	0	0.02727
14	0.09485	0	0.03000	41	0.08987	0	0.03333
15	0.09665	0	0.02128	42	0.09219	0	0.01818
16	0.09485	0	0.02000	43	0.10160	0	0.12500
17	0.08944	0	0.02459	44	0.10160	0	0.17500
18	0.09219	0	0.01818	45	0.09485	0	0.02000
19	0.09100	0	0.02609	46	0.08987	0	0.02500
20	0.09485	0	0.01000	47	0.09100	0	0.02609
21	0.09219	0	0.01818	48	0.09219	0	0.01818
22	0.09219	0	0.02727	49	0.09219	0	0.02727
23	0.09100	0	0.02609	50	0.09485	0	0.02000
24	0.09348	0	0.01905	51	0.09219	0	0.03636
25	0.09348	0	0.01905	52	0.09219	0	0.02727
26	0.09219	0	0.03636	53	0.08987	0	0.09167
27	0.09100	0	0.00870	54	0.09485	0	0.05000

Table 3 – Control limits and $\bar{L}_i$ values for FM chart

Lot No.	UCL	LCL	$\bar{L}_i$	Lot No.	UCL	LCL	$\bar{L}_i$
1	0.40598	0.25465	0.29318	28	0.40968	0.25096	0.37000
2	0.40432	0.25632	0.27391	29	0.40598	0.25465	0.29318
3	0.40276	0.25787	0.30417	30	0.40432	0.25632	0.34348
4	0.40968	0.25096	0.39750	31	0.39992	0.26072	0.34615
5	0.40598	0.25465	0.26818	32	0.40276	0.25787	0.35625
6	0.40777	0.25287	0.29762	33	0.40276	0.25787	0.36458
7	0.40598	0.25465	0.32955	34	0.40968	0.25096	0.38750
8	0.40276	0.25787	0.34375	35	0.40598	0.25465	0.38409
9	0.40598	0.25465	0.34773	36	0.40276	0.25787	0.40625
10	0.40968	0.25096	0.34250	37	0.41397	0.24667	0.40000
11	0.40598	0.25465	0.33182	38	0.40777	0.25287	0.33810
12	0.40968	0.25096	0.32500	39	0.40598	0.25465	0.31591
13	0.40432	0.25632	0.33261	40	0.40598	0.25465	0.33409
14	0.40968	0.25096	0.31250	41	0.40276	0.25787	0.34583
15	0.41217	0.24847	0.30585	42	0.40598	0.25465	0.28636
16	0.40968	0.25096	0.32500	43	0.41904	0.24159	0.38438

17	0.40217	0.25847	0.33402	44	0.41904	0.24159	0.40000
18	0.40598	0.25465	0.32045	45	0.40968	0.25096	0.31500
19	0.40432	0.25632	0.35000	46	0.40276	0.25787	0.27083
20	0.40968	0.25096	0.29500	47	0.40432	0.25632	0.28261
21	0.40598	0.25465	0.31591	48	0.40598	0.25465	0.25000
22	0.40598	0.25465	0.29773	49	0.40598	0.25465	0.35682
23	0.40432	0.25632	0.29783	50	0.40968	0.25096	0.33500
24	0.40777	0.25287	0.29048	51	0.40598	0.25465	0.34545
25	0.40777	0.25287	0.30952	52	0.40598	0.25465	0.32955
26	0.40598	0.25465	0.31364	53	0.40276	0.25787	0.36250
27	0.40432	0.25632	0.30000	54	0.40968	0.25096	0.42750

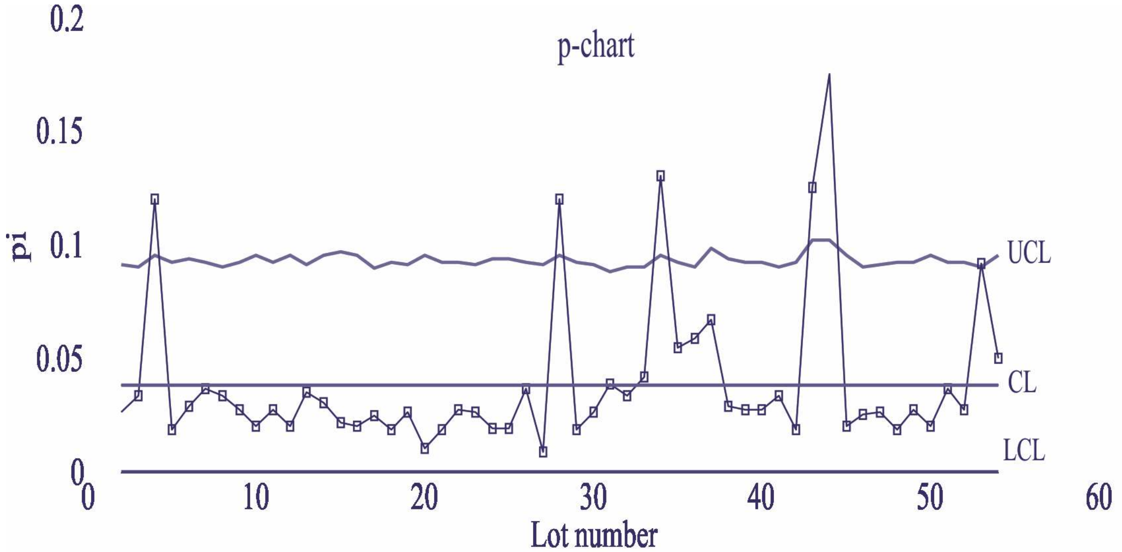

Fig.1 - *p*-chart for silk coccons

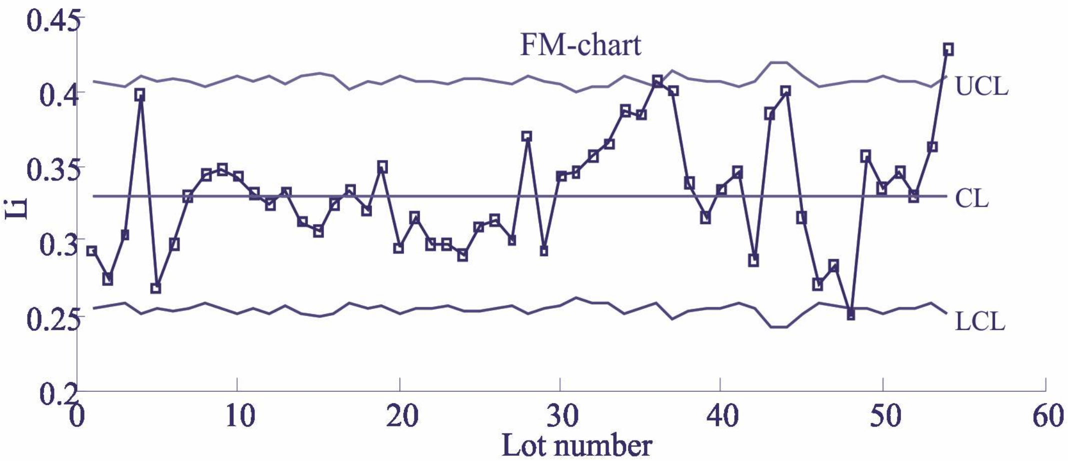

Fig.2 - FM-chart for silk coccons

Table 4 – Category wise probability

Lot No.	Reject(p_r)	Poor Quality(p_p)	Medium Quality(p_m)	Good Quality(p_g)	Excellent Quality(p_e)
1	0.02	0.11	0.15	0.46	0.25
2	0.03	0.09	0.12	0.49	0.28
3	0.03	0.11	0.14	0.48	0.24
4	0.12	0.13	0.16	0.40	0.19
5	0.02	0.08	0.14	0.48	0.28
6	0.03	0.11	0.17	0.39	0.30
7	0.04	0.10	0.20	0.47	0.19
8	0.03	0.13	0.19	0.48	0.17
9	0.03	0.15	0.19	0.46	0.17
10	0.02	0.16	0.20	0.41	0.21
11	0.03	0.13	0.19	0.45	0.20
12	0.02	0.11	0.20	0.49	0.18
13	0.03	0.13	0.17	0.47	0.20
14	0.03	0.10	0.18	0.47	0.22
15	0.02	0.11	0.16	0.50	0.21
16	0.02	0.14	0.19	0.42	0.23
17	0.02	0.14	0.16	0.49	0.18
18	0.02	0.10	0.22	0.47	0.19
19	0.03	0.14	0.18	0.51	0.14
20	0.01	0.09	0.17	0.53	0.20
21	0.02	0.12	0.16	0.51	0.19
22	0.03	0.12	0.15	0.44	0.27
23	0.03	0.11	0.17	0.42	0.28
24	0.02	0.11	0.15	0.44	0.28
25	0.02	0.10	0.16	0.52	0.19
26	0.04	0.11	0.13	0.53	0.20
27	0.01	0.10	0.13	0.59	0.17
28	0.12	0.12	0.06	0.52	0.18
29	0.02	0.10	0.12	0.56	0.20
30	0.03	0.14	0.20	0.45	0.18
31	0.04	0.14	0.17	0.48	0.18
32	0.03	0.17	0.18	0.44	0.18
33	0.04	0.18	0.16	0.45	0.18
34	0.13	0.10	0.19	0.35	0.23
35	0.05	0.15	0.22	0.45	0.14
36	0.06	0.22	0.17	0.41	0.15
37	0.07	0.22	0.09	0.49	0.13
38	0.03	0.12	0.20	0.47	0.18
39	0.03	0.12	0.14	0.53	0.19
40	0.03	0.15	0.15	0.50	0.18
41	0.03	0.16	0.15	0.48	0.18
42	0.02	0.11	0.17	0.40	0.30
43	0.13	0.13	0.15	0.36	0.24
44	0.18	0.10	0.10	0.40	0.23
45	0.02	0.12	0.17	0.48	0.21

46	0.03	0.08	0.13	0.47	0.29
47	0.03	0.11	0.15	0.39	0.32
48	0.02	0.07	0.15	0.40	0.35
49	0.03	0.19	0.16	0.42	0.20
50	0.02	0.15	0.20	0.41	0.22
51	0.04	0.14	0.19	0.45	0.19
52	0.03	0.12	0.18	0.49	0.18
53	0.09	0.10	0.19	0.40	0.22
54	0.05	0.25	0.19	0.38	0.13

6. RESULTS AND DISCUSSIONS

The *p*-chart for 54 multi-bivoltine hybrids silk cocoon lots are shown in Figure 1. The CL for *p*-chart is 0.037707 and Table 2 illustrates the p_i values and control limits for the *p*-chart. It can be illustrated from the *p*-chart of Figure 1 that lot numbers 4, 28, 34, 43, 44 and 53 are out-of-control. All this silk cocoons lots classified as 'reject' are nonconforming. Figure 2 represents the FM-chart for the 54 silk cocoon lots. The center line for FM-chart is 0.33032.Table 3 demonstrates the $\bar{\tilde{L}}_i$ values and the control lines for FM-chart. It can be seen from the Figure 2 that two different silk cocoon lots such as lot numbers 36 and 54 are found to be out-of-control.

The FM-chart considers the proportion of all categories such as reject (p_r), poor quality (p_p), medium quality (p_m), good quality (p_g) and excellent quality (p_e); whereas *p*-chart depends only on the proportion of rejected quality (p_r). Hence, any variations in p_p, p_m, p_g and p_e do not get reflected in *p*-chart if p_r remains constant. It can be explicated from comparison of both the charts that lot numbers 4, 28, 34, 43, 44 and 53 are out-of-control when only proportion of rejected silk cocoon (p_r) was considered in *p*-chart whereas lot numbers 36 and 54 became out-of-control in FM-chart when p_p, p_m, p_g and p_e are also registered in addition to p_r. The category wise proportion of all 54 lots are shown in Table 4. Table 4 demonstrates that proportion of reject quality silk cocoon is much higher in lot numbers 4, 28, 34, 43, 44 and 53 than lot numbers 36 and 54. But if p_r and p_p considered together, that proportion is higher in lot numbers 36 and 54 as compared to lot numbers 4, 28, 34, 43, 44 and 53.It means that more number of bad quality cocoons are present in lot numbers 36 and 54. Moreover, Table 4 illustrates the fact that among these eight lots, i.e., lot numbers 4, 28, 34, 36, 43, 44, 53 and 54, least proportion of excellent quality silk cocoons are available in lot numbers 36 and 54. Therefore, it can be resolved that as FM-chart have selected the right lots as the out-of-control product. The FM-chart consider all the details about the product and it can monitor the silk cocoon quality characteristic in better way than *p*-chart.

The lot number 48 is appeared just below the LCL in FM-chart shown in Figure 2.The LCL and UCL represent the lower and higher limits respectively for the proportion of bad quality silk cocoons. Therefore, if a lot falls near to the UCL in control chart, it indicates that the lot has more proportion of defective quality silk cocoon. Similarly better quality silk cocoons fall near to the LCL in FM-chart. Hence, the lot number 48 is basically better product. From Table 4 it can be perceived that lot number 48 is the best lot because it has highest p_e value amongst all the samples.

7. CONCLUSIONS

In this paper the fuzzy multinomial control chart with variable sample size is applied to characterize the silk cocoons quality. Being the natural product, silk cocoons qualities are completely fuzzy and imprecise. Hence, the attempt to silk cocoons quality characterization using fuzzy multinomial control chart is an accurate and novel approach. The FM-chart is capable to consider linguistic variables to determine the center line and control limits. The 54 lots of silk cocoons are assessed in five linguistic variables such as reject quality, poor quality, medium quality, good quality and excellent quality. The conventional *p*-chart is also compared with the FM-chart for silk cocoons quality characterization. It is observed that the six cocoon lots such as lot numbers 4, 28, 34, 43, 44 and 53 are found out-of-control in *p*-chart due to higher proportion of reject quality silk cocoons. But only two cocoon lots such as lot numbers 36 and 54 are found out-of-control when all five qualities are registered in FM-chart. Hence, it can be resolved that the FM-chart leads to a better result as it consider overall details of the product.

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REFERENCE

1. *R. L. Ramesh, L.S. Rakesh, S. Mukesh, E.N. Balkrishna, N. Sayyed & P.D. Kranti (2018), ISO 9001:2015 Quality Management System: Requirements, Interpretation and Application, India, Educreation Publishing.*
2. *W.A. Shewhart (1931), Economic Control of Quality of Manufactured Product, New Jersey, D. Van Nostrand Inc.*
3. *W. J. Kolarik (1995), Creating Quality- Concepts, Systems Strategies and Tools, McGraw - Hill.*
4. *D.C. Montgomery (2001), Introduction to Statistical Quality Control, New York, John Wiley & Sons Inc.*
5. *V. Amirzadeh, M. Mashinchi & M. A. Yaghoobi (2008), "Construction of Control Charts Using Fuzzy Multinomial Quality," Journal of Mathematics and Statistics, vol. 4 (1),2008,pp 26-31, 2008.*
6. *L.A. Zadeh, "Fuzzy sets," Information and Control, Vol. 8,1965, pp 338-359, 1965.*

7. H. J. Zimmermann, Fuzzy Set Theory and Its Applications, Boston, Kluwer Academic Publishers, 1996.

8. J H Wang & Raz T (1990), "On the construction of control charts using linguistic data," International Journal of Production Research, Vol. 28, 1990, pp 477-487.

9. T Raz & J. H. Wang (1990), "Probabilistic and membership approaches in the construction of control charts for linguistic data," Production Planning and Control, Vol. 1, pp147-157, 1990.

10. A. Pandurangan, & R. Varadharajan (2011), "Fuzzy Multinomial Control Chart with Variable Sample Size," International Journal of Engineering Science and Technology Vol.3(9),pp 6984-6991, 2011.

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