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Development of Multivariate Statistical Quality Control Charts for Quality Evaluation of Tilapia *(Oreochromis mossambicus)* (W. K. H. Peters, 1852) Stored in Chilled Condition

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The present study developed T^2 and SPE based multivariate control charts to evaluate and monitor the quality changes of tilapia *(Oreochromis mossambicus)* (W. K. H. Peters, 1852) Stored in chilled condition. Principal Component Analysis was performed to transform the correlated set of response variables into uncorrelated set of new variables. The first three principal components together explained 86% of total variability in the data. The same was used to develop T^2 and SPE based multivariate control charts to monitor the quality profile of tilapia during storage. The variability of response variable was within the confidence limits of control charts during storage. It was found that tilapia had 9 days of shelf life.

Keywords: Quality control charts, T^2 and SPE statistics, Tilapia, Shelf life

The shelf life of a fish depends on enzymatic, chemical, physical and biological changes that happen during storage, *ie*., the time from harvest to the level of unacceptability (Ashie et al., 1996; Berdanier, 2002). The quality of fish decreases as the number of days of storage increases (Huss, 1995; Hayes, 1985). There are several preservation methods that either arrest or delay the quality changes of fish during storage. Chill storage of fish is one of the several preservation techniques for maintaining the quality of fish by keeping the product at a low temperatures. Control charts are useful tools to monitor the quality changes of fish while assessing changes in multivariate response variables. The present study developed multivariate control charts to monitor the quality changes of tilapia (*Oreochromis mossambicus*) in chilled condition.

Tilapia (*Oreochromis mossambicus*) collected from Matsyafed, Njarakal, Kerala was used for the study. The average body length and weight of the fish was 20-23cm and 0.127-0.130 kg, respectively. Samples were transported to the laboratory in crushed ice, properly re-iced and stored in chill condition at 2°C. The quality assessment of chill stored tilapia was carried out by physical, bio-chemical, microbiological and sensory evaluation of samples. Fish samples were drawn daily to evaluate the quality changes during storage. The proximate composition was determined by AOAC (2012) method. TBA was determined by Tarladgis et al. (1980) and TVB-N was determined by method of Conway (1962). Sensory methods were used to assess the degree of freshness of tilapia based on organoleptic characteristics such as general body appearance (skin, scales, slime and stiffness), eyes (clarity, shape, iris and blood), gills (colour, mucus and smell), belly (discoloration and firmness),vent(condition and smell) and belly cavity (stains and blood) by a ten member sensory panel. Demerit score (DS) was assigned on a four point scale ranging from 0-3, where 0 represents high quality of fish and 3 represents poor quality of fish in terms of freshness of the sample. The cumulative total of demerit score ranged from 0 to 39 with 0 representing excellent quality of fish and 39 representing lowest quality of fish. Total plate count (TPC) was determined as per ICMSF (1986). Instrumental texture profile analysis (TPA) was done by Lloyd instruments, UK, Model LRX plus to objectively evaluate the texture of tilapia samples during storage.

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Multivariate quality control charts are very useful tools to monitor the variability in the quality changes in the fish during storage and also to identify the attributes responsible for unusual variation (Keunpyo et al., 2003). The present study developed multivariate quality control charts using T^2 and squared prediction error (SPE) multivariate statistics to monitor the quality changes in the tilapia during chill storage.

The quality attributes like TBA, TVB-N, DS, TPC, Hardness1, Cohesiveness, Springiness and Chewiness ($x_1, x_2, ..., x_p$) were measured during storage and assumed to follow multivariate normal distribution with mean vector $\boldsymbol{\mu} = (\mu_1, \mu_2 ..., \mu_p)'$ and covariance matrix Σ. The original measured and correlated variables (x_i's) were transformed into a new set of uncorrelated variables (y_j's) using Principal Component Analysis (PCA). The sample variance- covariance matrix '**S**' was computed from the observed values using the Equation (1) and same was incorporated in the principal component analysis (Johnson and Wichern, 2006)).

$$\mathbf{S} = \frac{1}{n-1} \sum_{j=1}^{n} (\mathbf{x}_j - \bar{\mathbf{x}})(\mathbf{x}_j - \bar{\mathbf{x}})' = \mathbf{PLP'}, \quad \text{.....................(1)}$$

where **P** is an orthogonal matrix whose column elements are the Eigen vectors of variance-covariance matrix and **L** is a diagonal matrix whose elements are Eigen values of sample variance-covariance matrix **S.** The j^{th} Principal Component is obtained as

$$\mathbf{y}_j = \mathbf{P'}(\mathbf{x}_j - \bar{\mathbf{x}}), \; j = 1,2,...,p, \quad \text{......................(2)}$$

The first 'j' principal components provide least square solution to the model given in Equation (3)

$$\mathbf{X} = \mathbf{YP'} + \mathbf{E}, \quad \text{................(3)}$$

where **X** is the n x p matrix of measured values of quality attributes, **Y** is the n x j matrix of first j principal components, **P'** is the j x p matrix of Eigen vectors and **E** is an matrix of error terms. The T^2 statistic for i^{th} sampling day is computed from j^{th} principal component model is expressed as

$$T^2_{ji} = \mathbf{y}_j' L^{-1} \mathbf{y}_j = (\mathbf{x}_j - \bar{\mathbf{x}})' \mathbf{S}^{-1} (\mathbf{x}_j - \bar{\mathbf{x}}) \quad \text{...........(4)}$$

The variability in the remaining p-j principal components is monitored through SPE statistic and it is computed as

$$\text{SPE}_i = \sum_{k=1}^{p} e^2_{ik}, \quad \text{.................. (5)}$$

where e_{ik} is the i^{th} error term of k^{th} quality attribute in the error matrix **E**.

The T^2 and SPE based control charts were obtained by plotting the values of T^2_{ji} and SPE_i against the sampling / storage days of tilapia in chill condition. The analysis of multivariate control charts was done by SAS 9.3.

Tilapia mince contained 78.1% moisture, 19.8% protein, 1.8% fat and 1.0% ash. The pH varied from 6.51 - 6.77 and water activity remained almost constant (0.99) during storage. The initial TBA and TVB-N values were 0.133 mg malonaldehyde kg^{-1} and 8.40 100 g^{-1}, which were increased to 0.347 malonaldehyde kg^{-1} and 19.00 100 g^{-1} on 9^{th} day of storage, respectively. The initial microbial load of

Table 1. Correlation between response variables.

	Correlation Matrix							
	TBA	TVBN	TPC	DS	Hardness1	Cohesiveness	Springiness	Chewiness
TBA	1.00	0.83	0.32	0.79	-0.69	0.50	0.25	-0.47
TVBN	0.83	1.00	0.35	0.97	-0.90	0.65	0.29	-0.60
TPC	0.32	0.35	1.00	0.46	-0.15	0.23	0.30	0.09
DS	0.79	0.97	0.46	1.00	-0.85	0.56	0.30	-0.56
Hardness1	-0.69	-0.90	-0.15	-0.85	1.00	-0.67	-0.10	0.84
Cohesiveness	0.50	0.65	0.23	0.56	-0.67	1.00	0.09	-0.37
Springiness	0.25	0.29	0.30	0.30	-0.10	0.09	1.00	0.29
Chewiness	-0.47	-0.60	0.09	-0.56	0.84	-0.37	0.29	1.00

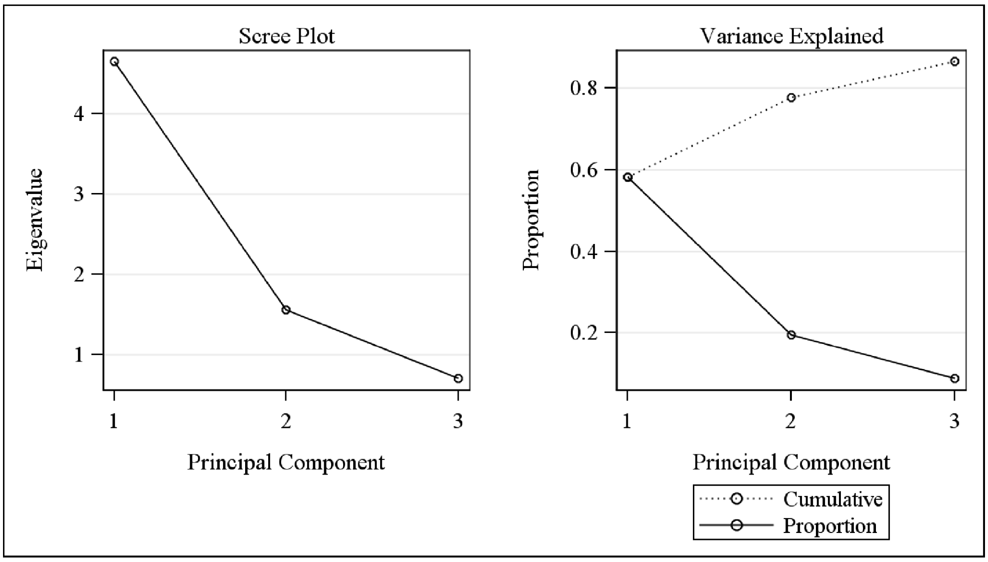

Fig. 1. Variance explained by principal components

the fish was 5.39 log cfu^{-1}, but due to the effect of icing there was a gradual decline in TPC upto 5th day, after which the value gradually rose to 6.60 log cfu^{-1} by 9 th day. The demerit score (DS) increased linearly and reached a score of 18 on 9th day of storage. The values of bio-chemical indices and DS was well within the acceptable limits on 9th day of storage, except the value of TPC. The hardness of fish sample was found to be decreasing with storage days, from 1469.6 to 30.29 N.

The correlation between the response variables is given in Table 1. The response variables were found to be positively correlated except for hardness and chewiness. The first three principal components (PC's) explained 86% of total variability in the data and these three PC's were selected in the study to develop multivariate quality control charts. The first, second and third PC's explained 58, 20 and 8% of total variability in the original data, respectively. This is depicted in the Fig. 1.

The multivariate quality control charts based on T^2 and SPE statistics are depicted in Fig. 2 and 3, respectively. It could be inferred from the multivariate quality control charts that there was no significant variability in the values of response variables till 9th day of rejection. The bio-chemical values of TBA and TVB-N were within the accept limits, but the TPC value crossed 6 log cfu^{-1} on 9th day of storage. This could be due to high initial microbial load and it was 5.39 log cfu^{-1} on first day.

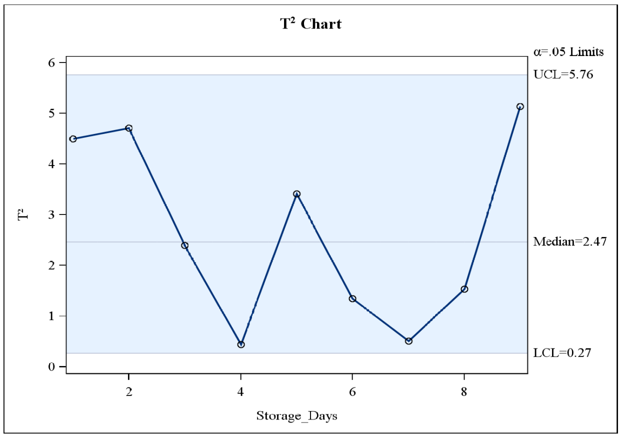

Fig. 2. Quality control chart based on T^2 statistic

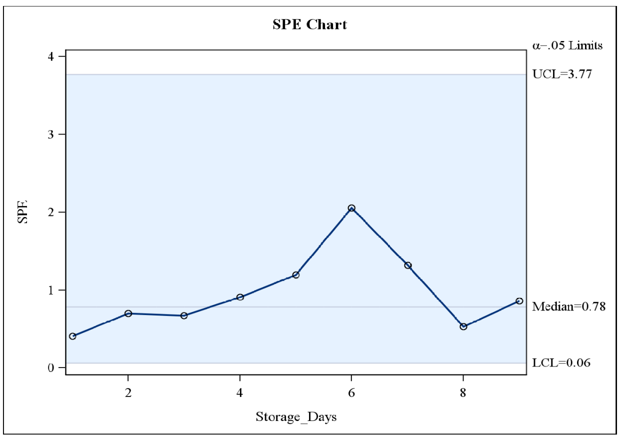

Fig. 3. Quality control chart based on SPE statistic

It was therefore observed that tilapia had a shelf life up to 9 days in chill stored condition.

The T^2 and SPE based multivariate quality control charts were developed and found to be very useful to monitor the quality changes of tilapia during chill storage. Tilapia had a shelf life of 9 days in chill storage and variability in the multivariate quality attributes were within the confidence limits of control charts.

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