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Improvement to quality management in supply logistics. Case study: aquaculture fishing company

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Abstract

The research was carried out in a fishing company in Sancti Spíritus, with the aim of improving the quality of the logistics system for the supply of aquaculture products, using predictive quality models. The proposal made it possible, with its partial implementation, to provide for the durability of fish products as a function of time and temperature of storage in the logistical supply system. In the course of the research and in designing the procedure, different methods and techniques were used: activity flow diagram, cause-effect diagram, Pareto chart, brainstorming, Delphi method, experiment design, quality index method, surveys, document consultation, among others. As a result, the relationship between the deterioration curves and the quality index method of the different treatments was obtained, which made it possible to obtain the predictive quality model of treatments 1, 2, 7, and 8, creating the conditions for decision-making in the evaluation of the quality of fresh aquaculture fish in the supply logistics of fishing companies.

Keywords: quality improvement; predictive models; logistics system; design of experiment; fishing industries.

Mejoramiento a la gestión de calidad en la logística de aprovisionamiento. Caso de estudio: empresa pesquera acuícola

Resumen

La investigación se realizó en una empresa pesquera de Sancti Spíritus, con el propósito de mejorar la calidad en el sistema logístico de aprovisionamiento de productos acuícolas, mediante modelos predictivos de calidad. La propuesta realizada permitió, con su aplicación parcial, prever la durabilidad de los productos pesqueros en función del tiempo y la temperatura de almacenamiento en el sistema logístico de aprovisionamiento. En el transcurso de la investigación y en el diseño del procedimiento, se emplearon diferentes métodos y técnicas: diagrama de flujo de actividades, diagrama de causa-efecto, diagrama de Pareto, la tormenta de ideas, método Delphi, diseño de experimento, método del índice de calidad, encuestas, consulta de documentos, entre otros. Se obtuvo como resultado la relación entre las curvas de deterioro y el método del índice de calidad de los diferentes tratamientos, lo que permitió obtener el modelo predictivo de calidad de los tratamientos 1, 2, 7 y 8, creándose las condiciones para la toma de decisiones, en la evaluación de la calidad del pescado fresco acuícola en la logística de aprovisionamiento de empresas pesqueras.

Palabras clave: mejoramiento de la calidad; modelos predictivos; sistema logístico; diseño de experimento; industrias pesqueras.

Introduction

Fish is one of the most complete foods of animal origin, due to the quantity and quality of nutrients it provides to the human body. It is indispensable for a balanced and healthy diet, mainly due to its valuable contribution in proteins of high biological value (15 to 24 %), as it contains essential amino acids essential for life, such as methionine, cysteine, threonine, lysine (essential for the growth of children) and tryptophan (essential for blood formation); as well as its rich content (0.1 to 15 %) in Omega-3 polyunsaturated fatty acids, docosahexaenoic acid, and eicosapentaenoic acid. In addition to this, its variable amounts of water-soluble vitamins, such as B1, B2, B3; and fat-soluble vitamins such as E, stand out. They provide potassium, iron, calcium (bones); and in smaller proportions iodine, magnesium, phosphorus, and zinc. To consolidate itself as a food whose benefit to the health of the consumer is increasingly evident [1].

On the other hand, fish is one of the most fragile and perishable products in existence, due to its high content in certain constituents such as water, with an average of 77,2 %, free amino acids, lipids with a high degree of unsaturation, non-protein nitrogen compounds, autolytic enzymes, etc.; which facilitate the initiation of a series of alteration pathways, either by alterations of endogenous origin, due to the activity of lipase enzymes that act on fats; or by alterations of exogenous origin where bacteria actively participate, carrying out processes of degradation of amino acids and amine oxides [1].

Perishable foods are those likely to spoil, decompose or become unsafe to eat [2]. They have a limited shelf life which depends on the characteristics of the product, the storage conditions in the product is kept and the time, which has resulted in an immense loss and waste of food, so they must be sold to consumers within the shelf life to ensure quality and safety, while maximizing profits [3].

The main operational causes of fish waste are inefficiencies in production, storage, handling and transport [4]. Therefore, the handling, preservation, storage, post-harvest measures, and transport of perishable foods require special attention to maintain quality and nutritional attributes, avoiding waste and losses [5].

The Food and Agriculture Organization of the United Nations has estimated that post-harvest losses (due to deterioration) continue to be 25 % of total catches. The best use of aquatic resources must therefore be directed, above all, at reducing these enormous losses, preserving fish and fishery products, and improving the quality of the logistical supply system [2].

Recent efforts focus on quality changes and predicting the shelf life of fish. Therefore, the use of models to predict quality changes is of considerable interest [6].

As a result of previous research and literature review [7, 8], the main losses in the quality characteristics of products derived from aquaculture fishing are found in the logistic supply system; where the shelf life depends on the characteristic of the product, the storage conditions in which the product is kept and the weather; and that there is no predictive model of quality changes, of common carp, based on storage time and temperature in the Cuban context. From this need it is recognized that the current practices for the evaluation of the quality of the common carp in the logistic of provisioning, does not allow the taking of opportune decisions, which causes post-harvest losses, constituting this the problem to solve. As a consequence, the objective of this research is framed in the design of a procedure to obtain a predictive quality model, that predicts the durability of fish products, according to time and temperature of storage, in order to make timely decisions that will reduce post-harvest losses.

Experimental

Based on the literature review carried out and the problematic situation, the research problem was answered by designing a procedure to obtain a predictive quality model, based on microbial analysis, total volatile basic nitrogen (TVBN), and sensory analysis; in the logistic management of supply to the aquaculture fishing industry. The procedure proposed in Figure 1 goes through 8 stages, partially applying it up to stage 3.

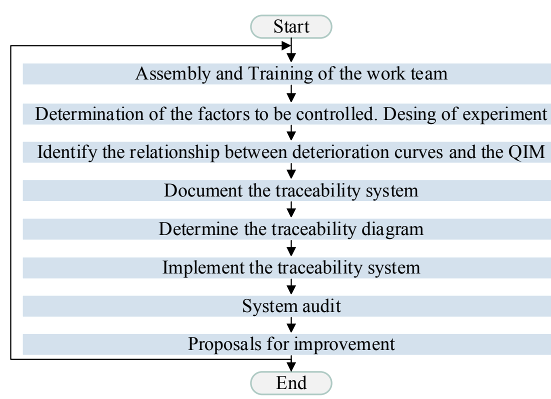

Figure 1. Stage in the procedure for the design of a predictive quality model for the supply logistics of the aquaculture fishing company. QIM: quality index method.

It starts with stage 1, for the execution of this step, the procedure approved in the NC 49:1981 [9] is recommended, and that the number of experts depends on the complexity and characteristics of the work to be done. The panel should be between 7 and 15 to maintain a high level of confidence and qualification [9]. Probabilistic criteria are used to determine the number of experts and a binomial distribution is assumed [10]. For this purpose, Equation 1 is used:

(1)

Where M: number of experts; i: desired level of accuracy; p: estimated proportion of errors by experts; k: constant whose value is associated with the chosen confidence level.

In stage 2, the factors affecting fish freshness and its durability are determined through methods and tools to be applied, such as: brainstorm, Delphi method and expert judge method, based on the calculation of the Kendall coefficient of concordance, the statistical design of experiment (DEE) procedure was applied, according to Gutierrez and de la Vara [11], which requires to take the following steps into consideration:

1. Determine the quality problem.
2. Determine factors to be studied or investigated.
3. Choose the response variables to be measured.
4. Select the appropriate experimental design for the available factors and the objective of the experiment.
5. Planning and organizing experimental work.
6. Carrying out the experiment.
7. Statistical analysis.
8. Interpretation.
9. Final conclusions.

The experimental results then make it possible to calibrate and support mathematical or computational models that are related to the phenomenon under investigation [12].

In stage 3, to determine the relationship between the deterioration curves and the quality index method (QIM, according to its acronym in English), the degree of logical association between the variables to be measured from the data collection, and subsequent analysis was represented in table form, required for confirmation of table mapping.

To document the traceability system in stage 4, Tables 1, 2, 3 and 4 were designed for data collection:

Table 1. Codification for the identification of raw material according to its origin.

Source	Fishing point	Fishing brigade	Code (raw material)		
Dam X	$X_1, X_2..., X_n$	Brigade Y	01: X	01: X_1	01: Y
Dam X	$X_1, X_2..., X_n$	Brigade Z	01: X	02: X_2	02: Z
Dam A	$A_1, A_2..., A_n$	Brigade Y	01: A	01: A_1	01: Y
Dam A	$A_1, A_2..., A_n$	Brigade Z	01: A	01: A_1	02: Z

Table 2. Label for the identification of fish lots.

Company logo				
Species	Tench	Carp	Tilapia	Clarias
Time of capture				
Collection point reception time				
Industry reception time				
Lot number	L- : ________________			

Table 3. Recorded parameters in the fish identification.

Parameter	Usefulness.
Name of the fish	Identification of the species.
Source	Identification of the reservoir where it was caught (origin of the fish).
Lot	Identification of the fishing brigade that made the catch. Delimitation of responsibilities.
Capture method	Fishing gear used (working methods and styles).
Exposure time	To know the exact time that elapsed from capture to Reception at the Collection Point in the aquaculture fishing establishment and then to Reception in the aquaculture fishing industry.
Characteristics of the fish	To state the characteristics that affect fish quality and safety. Determine the level of deterioration of the raw material.

Table 4. Control model for the identification of fish.

Control model for fish identification				**Month: ___________**		
Source:			Fishing brigade $_n$:	Method of capture:		
Date	Species	Time of capture	Time of arrival at collection point	Time of arrival in the industry	Demerit value of the collection point	Lot number

For the determination of the traceability diagram in stage 5, in the case of supply logistics to the aquaculture fishing industry, traceability is internal and will be facilitated through the monitoring of the batches associated with the fishing brigades identified by codes, thus, the logic on which the revision of the traceability processes is based was followed, through compliance with the three principles: identification, registration, and transmission.

Once the raw material data has been identified, in stage 6, timely decisions will be guaranteed focused on two fundamental aspects: prioritizing the entry of the raw materials into the industrial process; and determine what assortment to make depending on the fish level of deterioration, which will make it possible to reduce post-harvest losses.

In stage 7, systematic checks established to evaluate the proper functioning of the system and its effectiveness, as well as the detection of possible improvements.

In this stage 8, the reduction of post-harvest losses evaluation is proposed, once the traceability system has been implemented in the logistics of supply to the aquaculture fishing industry. Trend graphs and control graphs by variables can be used as a fundamental tool.

Results and Discussion

For the application of the procedure, each of the stages depicted in figure 1 was addressed, for the sake of the logical sequence of work.

Stage 1. Assembly and Training of the work team

The number of experts was calculated using Equation 1, where: i= 0.1, confidence level= 99 %, p= 0.01, k= 6.6564; where a total of seven experts were obtained. From this analysis, those with an expert competence coefficient (k) that were closest to the value 1 were selected.

Stage 2. Determination of the pre- and post-harvest factors to be controlled. Design of experiment

Once the experts were selected, a brainstorming process was applied to identify all the pre- and post-harvest factors that affect the fish freshness. Then, the Delphi method was used because of its suitability in validating the factors established as most appropriate, according to the conditions of the culture media and the conditions of the company. For this purpose, each of the selected experts was given a questionnaire to obtain criteria on the procedure to be applied, and using a *Microsoft Excel* spreadsheet, the criteria of the selected experts was processed to validate the procedure. It was structured as follows:

Using a table, the criteria of each expert were recorded and the criteria and categories of the scale were taken as variables (very adequate= 1, fairly adequate= 2, adequate= 3, poorly adequate= 4 and inadequate= 5); an absolute frequency table where the aspects and categories of the scale were taken as variables; a table of absolute cumulative frequencies; a table of relative cumulative frequencies; and a table that made it possible to determine the cut-off points and the scale of the aspects considered. The points were obtained through the calculation of N-P, where: $N=\frac{\Sigma\,\text{Sum by aspects}}{\text{Number of ratingranges}\cdot\text{Number of aspects}}=\frac{146.95}{75}=1.959$; y P= Average by aspects.

When the condition: N-P <Cut-off point (-1.047<-0.118) is met, the expert opinion is valid. In this sense, it was concluded that the pre- and post-harvest factors that most affect the carp quality and safety, and therefore need to be taken into account in any study to be carried out, are: species, age, weight, production conditions, water temperature, chemical contamination, microbial contamination, poor handling and transport practices, time-temperature phase, non-compliance with health standards and preservation of the cold chain.

Application of the statistical experiment design procedure:

1. The company under study does not keep records of post-harvest losses, hence, studies in developing countries are used as a reference. The following are defined as indicators to measure the success of the improvement project: industrial performance; time/temperature relationship and use of ice per tonne of capture.

Table 5. Test levels for each factor significantly influencing the response variable.

Production condition		Contamination of the reservoir (CR)			
		- Less contaminated point		+ Most contaminated point	
		Cold storage capacity (SC)		Cold storage capacity (SC)	
		+ In the capture	- On the ground	+ In the capture	- On the ground
Environmental temperature (ET)	- Morning shift	-ET-CR+SC (1)	-ET-CR-SC (2)	-ET+CR+SC (3)	-ET+CR-SC (4)
	+ Afternoon shift	+ET-CR+SC (5)	+ET-CR-SC (6)	+ET+CR+SC (7)	+ET+CR-SC (8)
Fishing gear: mouth; species: common carp; age: 2-3 years; and weight: 1.8-2.3 kg					

2. Among the factors that significantly influence the response variable are: species, age, weight, production conditions and contamination of the reservoir, which are considered input variables. The test levels for each factor are shown in Table 5:

3. The quality characteristics derived from the microbiological and sensory analysis that are expected to reflect changes in controllable and uncontrollable factors and can be reliably measured are: Escherichia coli, colonies of microorganism, coliforms, thermotolerant coliforms, skin, rigidity, eyes, and gills.

4. Factorial design 2^k is selected (k factors with two levels each) and within this the 2^3 model, because three factors that affect the response variable, and therefore ($2 \leq k \leq 5$) factors need to be studied. It consists of 2^3= 8 different treatments.

The estimate of the number of fish to be run in each treatment was calculated with the following Equation 2:

$$m = (2.5)^2 \left(\frac{1 - p_0}{p_0}\right) \quad (2)$$

Where p_0 is the ratio used as a basis and $(2.5)^2$ a constant; in this experiment p_0= 0.6 and when it is substituted in Equation 2, it is obtained that m= 5 fish per treatment, to detect the effects on each factor in satisfactory way.

With the complete factorial design 2^3 the 2^{k-1} effects can be studied in total, as shown in Equation 3:

$$\binom{k}{r} = \frac{k!}{r!(k-r)!} \quad (3)$$

With this Equation 3, are obtained as result, 3 main effects, 3 double interactions and 1 triple interaction, which gives a total of 7 effects.

5. We worked with: the group of selected experts, samples of fish caught in the Zaza dam belonging to the “PESCASPIR” fishing company in the morning and afternoon hours, at the most and least polluted point of the reservoir and part of the samples were frozen on the boat and the rest when it reached land. Then, these samples were taken to the Sancti Spíritus industrial fishing company “EPISAN”, where the corresponding tests were carried out.

6. In this experimental phase, the maximum limit of micro-organisms at 30 °C that can be present in common carp to be considered safe for human consumption was determined (up to $1.0*10^5$ CFU per gram, according to NC 585:2017 [13]). Coliforms at 45 °C in common carp are considered harmless as long as their value is zero, which means that, from the presence of these bacteria in the species, it is deteriorated. As the presence of coliforms was determined at 45 ºC, from treatment 1 to the ninth day and the treatment 2 to the seventh day, microbial growth values remained the same until that day; for treatment 7 and 8 it remained innocuous until the fourth and fifth day respectively (Table 6).

Table 6. Microbiological analysis of the quality parameter microbial growth of common carp caught at 10:00 am shift (CFU per gram).

		Days stored in ice								
		1	2	3	4	5	6	7	8	9
Treatments	1	148	1800	1960	2258	2848	5240	62600	90600	99800
	2	742	2000	3260	3760	6920	59540	86800	-	-
	7	410	940	5280	5760	5920	-	-	-	-
	8	422	1620	5660	5800	-	-	-	-	-

With the data obtained in the previous stages and through the QIM (Table 7), the necessary sensory analyses were carried out to detect the deterioration of common carp to the point where it ceases to be harmless to human health. Overall sensory analysis with a demerit score, where the total sum range between 0 (total freshness) and 22 (total loss of freshness), showed that common carp in ideal conditions can reach up to nine days of storage in ice if caught in the morning shift, while in unfavorable conditions only up to seven days at the same schedule (Table 8).

Table 7. Quality parameters for freshness in fish indicator measurement.

	Quality parameters	**Scores**
	Appearence/color	0 --- 2
Skin	Mucus	0 --- 2
	Smell	0 --- 3
Rigidity/texture		0 --- 3
Eyes	Cornea	0 --- 3
	Pupil	0 --- 2
	Adherence	0 --- 3
Gills	Color	0 --- 2
	Smell	0 --- 2
	Quality Index	**0 --- 22**

Table 8. Values by demerits of the sensory analysis to the common carp freshness quality parameter caught at 10:00 am shift.

	Days stored in ice								
Treatments	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1	0	0	1	2	3	4	8	14	22
2	0	2	3	3	7	12	19	22	-
3	0	0	1	8	9	15	20	22	-
4	0	0	6	10	16	19	22	-	-
5	0	1	2	3	3	10	15	22	-
6	0	2	3	5	11	18	22	-	-
7	0	0	4	9	13	17	22	-	-
8	0	1	8	10	15	21	22	-	-

7. An analysis of variance was carried out (ANOVA, Tables 9 and 10) for all microbiological and sensory parameters, with simultaneous 99 % confidence intervals and Tukey test and an individual confidence level of 99.96 %.

Table 9. ANOVA: general microbiological analysis vs. days.

Source	Degree of freedom	Sum of squares	Middle square	F value	p value
Day	8	23121215834	2890151979	25.76	0.000
Error	16	1794788097	112174256		
Total	24	24916003930			

S= 10591 R^2= 92.80 % R^2 (adjusted)= 89.19 %

F: variation between samples averages/variation within samples, and p: proportion.

Table 10. ANOVA: general sensory analysis vs. days.

Source	Degree of freedom	Sum of squares	Middle square	F value	p value
Day	8	3147.1	393.4	27.48	0.000
Error	52	744.4	14.3		
Total	60	3891.4			

S= 3.784 R^2= 80.87 % R^2 (adjusted)= 77.93 %

F: variation between samples averages/variation within samples, and p: proportion.

It is verified that significant differences exist under the more or less favorable conditions of the statistical experimental design, for all the microbiological and sensorial parameters (p= 0.000, p >0.01), which shows that the contamination of the reservoir, the ambient temperature, and the cold storage capacity, influence the timely decisions for the industrial processing of common carp.

8. In the microbiological analysis, only the deterioration curves of treatments 1, 2, 7, and 8 were carried out. The other treatments were not analyzed because of the test cost. Figure 2 shows the microbiological analysis, in which it was determined that the common carp species in the ideal conditions of pre- and post-harvest has a total duration of nine days of storage in ice if caught at 10:00 am shift, otherwise it is considered innocuous for the human consumption until the fourth day.

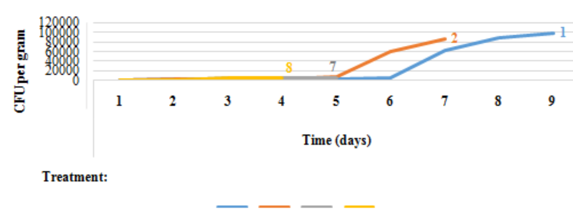

Figure 2. Analysis of common carp product useful life in relation to the CFU per grams count.

In the sensory analysis, the deterioration curves of the 8 treatments were carried out, as shown in Figure 3. In this analysis, it was determined that under ideal pre- and post-harvest conditions it has a total duration of nine days of constant storage in ice, while under the most unfavorable conditions it is considered safe for human consumption until the seventh day.

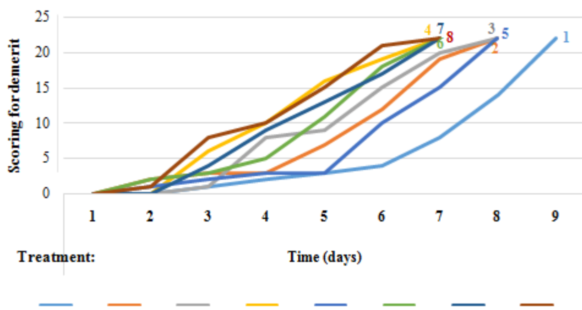

Figure 3. Analysis of common carp product useful life according to the demerit score in Table 7.

9. According to the analyses carried out, it is confirmed that the common carp in relation to the microbial growth and the score by demerit, has a maximum duration in the optimal conditions of manipulation, storage and transport of the culture medium, among others, of 9 days; so that to generalize the result of the experimental design, and in this way achieve that the improvements are maintained, the correct hygienic-sanitary norms handling rules must be followed, the cold chain must be maintained from the moment the fish is captured and, if the conditions are not ideal for this, it must be cold stored as soon as the boat arrives at port. Always should be taken into account the capture schedule, fishing points, age, weight of the carp, and fishing gear.

Stage 3. Determine the relationship between the deterioration curves and quality index method

At this stage, the relationship between the impairment curves and QIM, where only the maximum and minimum useful lifetime limits were taken into account, which is shown in Table 11.

Table 11. Relationship between the deterioration curves and quality index method of the maximum and minimum useful lifetime limits of treatment 1, 2, 7 and 8.

Maximum lifetime limit	Treatment 1 (-ET-CR+SC)	**Day**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
		Scoring for demerits	0	0	1	2	3	4	8	14	22
		Microbial growth (CFU.g-1)	148	1800	1960	2258	2848	5240	62600	90600	99800
	Treatment 2 (-ET-CR-SC)	**Day**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**-**
		Scoring for demerits	0	2	3	3	7	12	19	22	-
		Microbial growth (CFU.g-1)	742	2000	3260	3760	6920	59540	86800	-	-
Minimum lifetime limit	Treatment 7 (+ET+CR+SC)	**Day**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**-**	**-**
		Scoring for demerits	0	0	4	9	13	17	22	-	-
		Microbial growth (CFU.g-1)	410	940	5280	5760	5920	-	-	-	-
	Treatment 8 (+ET+CR-SC)	**Day**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**-**	**-**
		Scoring for demerits	0	1	8	10	15	21	22	-	-
		Microbial growth (CFU.g-1)	422	1620	5660	5800	-	-	-	-	-

In obtaining the predictive model (Table 11), how the value of the variable (scoring for demerits) increases with the value of the variable (Microbial growth CFU.g^{-1}) for each of the treatments 1, 2, 7 and 8, is classified as a strong positive relationship.

Conclusions

The partial application of the designed procedure made it possible to identify the pre- and post-harvest factors, which most affect the fish freshness (species, age, weight, production conditions, water temperature, contamination of the reservoir, poor handling and transport practices, time-temperature phase, non-compliance with health standards and preservation of the cold chain). Input variables influencing response variables were defined (species, age, weight, production conditions and contamination of the reservoir) and measured be microbiological methods, and the quality index method (QIM). The different treatments (from 1 to 8) to be studied in the experimental design were identified (2^k= 23= 8). In the procedure, it was also determined that there are significant differences between the most favorable and least favorable conditions of the identified treatments. As a conclusion of the statistical experiment design, it was found that common carp in relation to microbial growth and demerit score, has a maximum duration of 9 days, maintaining optimal conditions of handling, storage and transportation. Besides, the relationship between the deterioration curves and QIM of the different treatments was determined, which made it possible to obtain the predictive quality model for treatments 1, 2, 7, and 8. In this way, practices for evaluation the quality of fish in the logistical supply system obtain more reliable information on the durability of fish products and facilitate timely decision making for the sake of post-harvest losses reduction.

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