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APPLICATION OF PARETO PRINCIPLE IN MONITORING WALNUTS QUALITY AT STORAGE

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Abstract. This paper presents two case studies of walnut quality assessment at room temperature storage of 20 ± 2^{0}C. The conformity of the Juglans regia L. walnuts, the Calarasi variety, (harvest 2015) and Cogalniceanu variety (harvest 2016) was analyzed by applying the *Pareto* diagram and *nP*-card. These methods present a process of risk analysis, involves obtaining, analyzing and modeling information, analyzing and adopting a decision that improves the product quality. The data were collected during storage of walnuts at room temperature 20 ± 2° C for 6 and 12 months, respectively. The external and internal defects of walnuts have been assessed and grouped by risk categories. The most widespread defects of walnuts, which diminish their quality and the weight of their use on an industrial scale have been emphasised. It has been found that temperature and humidity are critical factors when storing walnuts. It is proposed a primary scheme for the in shell walnuts processing.

Keywords: *walnuts quality, diagram Pareto, nP-card, defects frequency.*

Introduction

Quality in the food manufacturing industry can be defined in different ways. One definition of quality is meeting or exceeding customer expectations and requirements [3, 25]. This aspect of quality certainly applies to the food industry as customers expect nutrition, good taste and pleasing appearance in the products they purchase. Another definition of quality that is appli-cable to the food industry is the assurance that the product is safe to eat and that the food is sanitary and has a maintained integrity that is without physical or chemical contamination [1-3, 26]. Many consumers expect pleasing appearance and taste and that the food is safe to eat. Two parameters can be used to address quality within the food industry. The first is Failure Mode and Effects Analysis (FMEA), which is widely used within multiple industries to improve and manage overall quality. The second is more commonly used for the food safety aspects of quality, Hazard Analysis and Critical Control Points (HACCP), which identifies potential safety risks in food products and proactively seeks to reduce or eliminate them [25]. A risk analysis process involves acquiring information, modeling, analyzing the information and the model and coming to a decision that improves the product [17, 20]. There are five approaches that can be identified in practice [4, 10]: Safety-based root cause analysis; Production-based root cause analysis; Process-based root cause analysis; Failure-based root cause analysis; Systems-based root cause analysis. The Pareto chart aims to [15, 16, 21, 22]:

- Separate important issues from potential ones so you can focus on improving them,
- Arrange information by priority or importance,
- Help determine the important issues based on information rather than opinion.

The basic process consists of a number of basic steps. These corrective measures will lead to the true cause of the problem: identifying the problem; setting the improvement target; case analysis; formulation of improvement proposals; implementing the improvement plan; evaluating the results of the improvement; ensuring that the problem is not repeated [9, 10, 27]. The Pareto diagram presents the following advantages [16, 27]:

- Graphical representation highlights the causes of defects, as support for making decisions.
- By comparing diagrams made before and after taking corrective or improvement measures, it is possible to highlight the progress made in revolving problems [15].

Methodology of the research

To carry out the research work the following methodology were used.

- **Problem Indentification**: Within the project nr. 15.817.02.30A „Methodological and technical elaboration for the modernization of the walnut prosessing technoloy (Juglans regia L.) with use of biologically active components in functional food „NUCALIM –PROBIO" „ a walnut game was purchased, which was later used for scientific research. It was noted that during the storage period there was a mismatch in the purchase of walnuts.
- **Data Collection:** The data were collected from October 2015 to March 2016.
- **Data Analysis:** Analyzed defects in April 2016
- **Implementation of Quality Control Tools**: The tools used were sampling, *nP*-card, Pareto analysis, and flow diagram. With the help of these tools the main causes came out which were highly responsible for the walnut quality.
- **Remedies / Action Taken:** the modified and corrective actions were taken into account at the next purchase of the walnuts for the project's research nr. 15.817.02.30A.
- **Standardization:** After the implementation of the quality control tool and the actions taken, the problem was solved.

If the number of defects classified by category is noted: n_c, n_p, n_s, n_m, and the weights of the respective defects: P_c, P_p, P_s, P_m, of a sample with total number ***N,*** in this case the quality is appreciated by the index ***D*** depending on the deviations from the excellent quality indicators through the relationship:

$$D = \frac{P_c n_c + P_p n_p + P_s n_s + P_m n_m}{N} \quad (1)$$

Quality can also be assessed and fixed on the basis of standards, technical prescriptions ***(D_0)***. In this case, the index that reflects losses in the quality (***I_D***) of a food being examined is defined by the report:

$$I_D = \frac{D}{D_0} \qquad (2)$$

I_D index values can be next:

a) **I_D = 1,** quality is the same as the reference ***(D_0);***

b) **I_D < 1,** quality is superior to the reference;

c) **I_D > 1,** quality is inferior to the reference.

The method that judges deviations from excellent quality indicators is called demerit and it is used for any control method: wholly through sampling or reception. The order of defects according to the frequency is done by *Pareto analysis (chart)*.

Pareto chart. The Pareto diagram was created by plotting the frequency of the relative frequency of the causes in descending order, after which the essential factors for analysis are graphically formatted and ordered [8, 14, 28]. The Pareto chart helps to guide interventions methodically through action plans built around the major causes of emerging issues, being a visually-oriented, instrumental tool to make the decision. It is a qualitative analysis tool because it focuses on process parameters through the frequency of occurrence. Defined parameters can be events, errors, features, etc. [2, 8, 11, 14].

nP – control chart.

This chart served the basis of the statistical method for testing and assessing the quality of the batch of Calarasi variety walnuts, the harvest year 2015 and consists in analyzing the number of damaged walnuts in the examined batch. According to the nP - chart method the number of walnuts in each sample was 20. Following the analysis of the samples, the number of defective nuts was determined on the basis of which the tolerance limits were calculated. The upper and lower tolerance bands (LTS and LTI) appreciate the permissible variation limits of the number of damaged walnuts in the test lot.

The distribution of defective walnuts relative to the average value of total walnuts is characterized by the Student distribution coefficient**.** Based on ***3σ*** concept, according to the Student distribution and applying the relations (5) and (6), the LTS and LTI tolerance limits were calculated relations (Student coefficient equal to k = 3,0).

Experimental data: 15 selections were used and analyzed with 20 walnuts in each selection. The number of defective nuts (p) has been identified in each selection.

n **-** The number of walnuts in a sampling batch;

p_i – total number of nuts with defected kernel;

m - total number of batches.

***∗ Average number of defective walnuts in a sampling batch*:**

$$\mathbf{np} = \frac{\sum p_i}{\sum m} \qquad (3)$$

Tolerance Limit:

$$LA = np \pm k \sqrt{np\left(1-\frac{np}{n}\right)} \quad (4)$$

Superior tolerance limit ***(LTS):***

$$LTS = np + k \sqrt{np\left(1-\frac{np}{n}\right)} \quad (5)$$

Inferior tolerance limit ***(LTI):***

$$LTI = np - k \sqrt{np\left(1-\frac{np}{n}\right)} \quad (6)$$

Table 1 includes defects in food products grouped by the risk they pose to consumers.

Table 1.

Classification of defects by category [27]

Defect type	Defect definition
Critic	Defect that prevents use of the product, producing rebut, risk to the health of the consumer
Primary	Reduces the possibility of using the product causing some inconvenience to the consumer. It generally produces complaints
Secondary	In principle, it does not affect the possibility of use; is perceptible to consumers but does not generate complaints
Minor	Does not reduce usage; do not pose serious inconvenience to consumers

This experimental study examined the defects of Junglans regia L. walnut harvested in Moldova and stored under laboratory conditions. The defects have been studied on the basis of the Government Decision, on the approval of the Technical Regulation "Nut fruit crops. Quality and marketing requirements". Table 2 shows the defects of shelled and unshelled walnuts on the basis of the regulations on fresh walnut tolerance [21]. Quality and size tolerances shall be allowed in each package for products not in conformity with the requirements of the category indicated (Table 2).

Table 2.

Walnuts defects regulated by the Technical Regulation "Nut fruit crops. Quality and marketing requirements "

The allowed defects	Allowed tolerances, %		
	Category super	Category I	Category II
a) Total tolerance for shell defects	7	10	15
b) Total tolerance for the defects of the party edible *	8	10	15
c) Of which nuts are eaten, rotted or attacked by insects	3	6	8
Including nuts moldy**	3	4	6

[*] For fresh nuts, tolerance of kernel defects is: Extra- 8% , 1st category -12%, 2nd catergory – 15%.
** Live insects or animal pests are not allowed in any category.

Determination of defects in shelled walnuts.

Defects of the shell are considered defects that alter the appearance, such as [21]:

1) color change: uncharacteristic stains or color, which comprise 20% of the surface of the shell of the nut, and which has a brown, brownish, gray or other color, contrasting net with the rest of the shell or most of the shells in the batch;
2) dirt, sticky soil comprising more than 5% of the surface of the shell;
3) adherent shell comprising more than 10% of the shell surface;
4) Traces of decay: traces pronounced on the shell, resulting from the mechanical removal of the shell.

Walnuts defects are considered to be:

1) defects that alter the appearance of the core, such as stains or discolored areas: a color change of more than a quarter of the core, and a hue that contrasts with the core;
2) Spattered cores - considerably creased, dried and hardened cores.

Results and discussion

The article presents two case studies of Junglass regia L walnuts quality change during storage at ambient temperature of 20± 2^0 C:

- Variety **Calarasi,** harvest 2015, storage time 6 months;
- Variety **Cogalniceanu,** harvest 2016, storage time 12 months;

Walnuts were purchased under project no. 15.817.02.30A „Methodological and technical elaboration for the modernization of the walnut prosessing technoloy (Juglans regia L.) with use of biologically active components in functional food „NUCALIM –PROBIO”.

Table 3 presents the results of the Calarasi variety examination, 15 lots of walnuts, each containing 20 walnuts were sampled.

Table 3.

Defects found in nuts, Calarasi variety

Lot no.	Walnuts external defects			Walnuts inner defects		
	Walnuts with defects	**Defect description**	**Frequency, %**	**Walnuts with defected kernel**	**Defect description**	**Frequency, %**
1.	3	3 nuts with black spots on the shell. When the walnuts were broken, two had a good kernel.	15	1	Dark kernel	5
2.	-	-	-	5	3- black, 1 - dry, 2 - molds	25

Continuation *Table 3*

3.	5	5 nuts with black spots on the shell. When broken, a nut had a good kernel	25	3	2 – affected by larvae; 1- black with mold	15
4.	-	external defects have not been detected	-	4	1 – black kernel; 2 – inner mold; 1 – black and dry kernel.	20
5.	2	2 walnuts completely black outside	10	2	1 – black kernel; 1 - dry kernel.	10
6.	-	external defects have not been detected	-	3	2 – black kernel; 1 – kernel with mold	15
7.	-	external defects have not been detected	-	-	inner defects have not been detected	-
8.	1	black surface, partly with mold	5	4	2-black kernel; 1-partially dry; 1- black with mold.	20
9.	1	Black spots	5	3	1- black kernel; 1 – kernel with mold; 1 – dry kernel.	15
10.	-	-	-	-	-	-
11.	-	external defects have not been detected	-	6	1– black kernel; 1 – infested kernel; 2 – dry kernel.	30
12.	2	Black spots outside	10	4	2 – black kernel; 1 – infested kernel; 1 – dry kernel.	20
13.	1	Black spot outside	5	4	1 –kernel with mold; 1 –infested kernel; 1 – black and partially dry kernel.	20
14.	2	2 walnuts completely black outside	10	1	1-black kernel.	5
15.	-	external defects have not been detected	-	4	3 – black kernel; 1 – dry and infested kernel	20
∑	**17**		**5,67**	**44**		**14,67**

According to the experimental data presented in Table 3, two categories of walnut defects were analyzed:

1) External defects of walnuts (walnut skin). Following analysis, the following defects were identified: black spots, completely black shell.
2) Inner defects of walnuts (walnut core defective). Following analysis, the following defects were identified: blackened, dry, black core with mold.

Analyzing the defects found in the 15 batches of tested walnuts, 6 types of defects were identified, which are presented in Table 4.

Table 4.

Percentage of walnuts waste Based on Their Categories

Nr.	Walnuts Defect Type	Number of defects	Cumulative number of defects	Cumulative number of defects, %
1.	A dark core, internal defect **(A)**	21	21	34,43
2.	Color change, external defect (**B**)	12	21 + 12 = 33	54,01
3.	Core with mold (**C**)	12	33 + 12= 45	73,77
4.	Dry core, internal defect (**D**)	11	45 + 11 = 56	91,80
5.	Traces of decay, external defect (**E**)	3	56 + 3 = 59	96,72
6.	Adherent shell, external defect (**F**)	2	59 + 2 = 61	100
	Total defects	61		

For the quantitative interpretation and hierarchy of the main defects according to the frequency of their occurrence, the Pareto analysis was performed. The Pareto principle is also called the 80/20 rule, which states that 80% of the effects (quality defects) occur as a result of only 20% of the existing causes.

According to statistical analysis of the 15 samples of tested walnuts non-compliant walnuts were found to be 15%. The upper tolerance limit of the non-conforming nuts was 8 pieces, or 3% of the total tested lot.

Analyzing the category and the percentage of defects in selected sample samples, the same results were identified by other authors. One of the important factors in the quality of nuts during storage is the way of harvesting the fruit.

In order to correctly determine the moment of in shell walnut harvesting, several factors are taken into account, considering that nuts maturing does not take place on all the trees and never on the same tree [12]. Premature harvesting of walnuts leads to considerable loss of product (25-40%) but especially to deterioration of its quality. Nuts collected before physiological maturity are dried, the kernel is wrinkled containing few albumins, fats and sugars and tastes non-specific to walnuts. Moreover, the walnuts that were harvested early are very hard to remove the green peel, which leads to the loss of their quality [18].

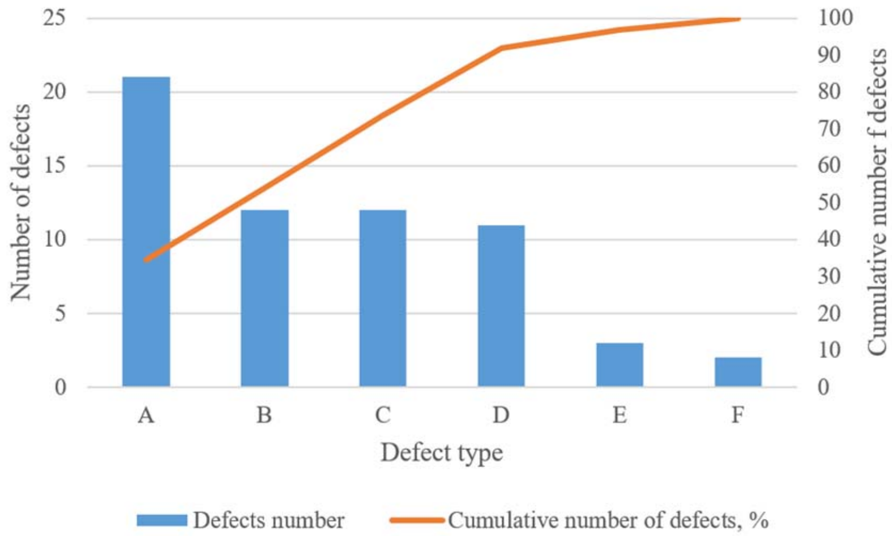

Figure 1. *Pareto chart*. The cumulative weight of Calarasi variety walnuts defects.

np chart analysis

Data of case study:15 samples were selected and analyzed with 20 walnuts in each sample. The number of defective nuts (***p***) has been identified in each sample:

Table 5.

Characteristics of walnut samples

	Number of samples														
M	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
N	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
P	1	5	3	4	2	3	0	4	3	0	6	4	4	1	4
%	5	25	15	20	10	15	0	20	15	0	30	20	20	5	20

Where: ***n*** **-** walnut number in one sample, **n = 20**:

p_i – number of walnuts with defected kernel, **Σp_i =44**

m - number of samples, **m =15**

Table 6.

Parameters of walnut batches for *np chart* elaboration

No.	Parameter	Calculated value	References to the calculation formula
1.	Average number of defective walnuts in a sampling batch **(np)**	3,0	(3)
2.	*Tolerance Limit* (LA)	3	(4)
3.	*Superior Tolerance Limit* **(LTS)**	0	(5)
4.	*Inferior Tolerance Limit* **(LTI)**	8	(6)

According to the ***3σ*** conception in a batch of examined walnuts, the content of defective walnuts is determined with the accuracy of 99, 73%, i.e. the potential for error is admitted no more than 0.27%. At the same time, the number of walnuts without defects of quality is (100-0,27 = 99,73%).

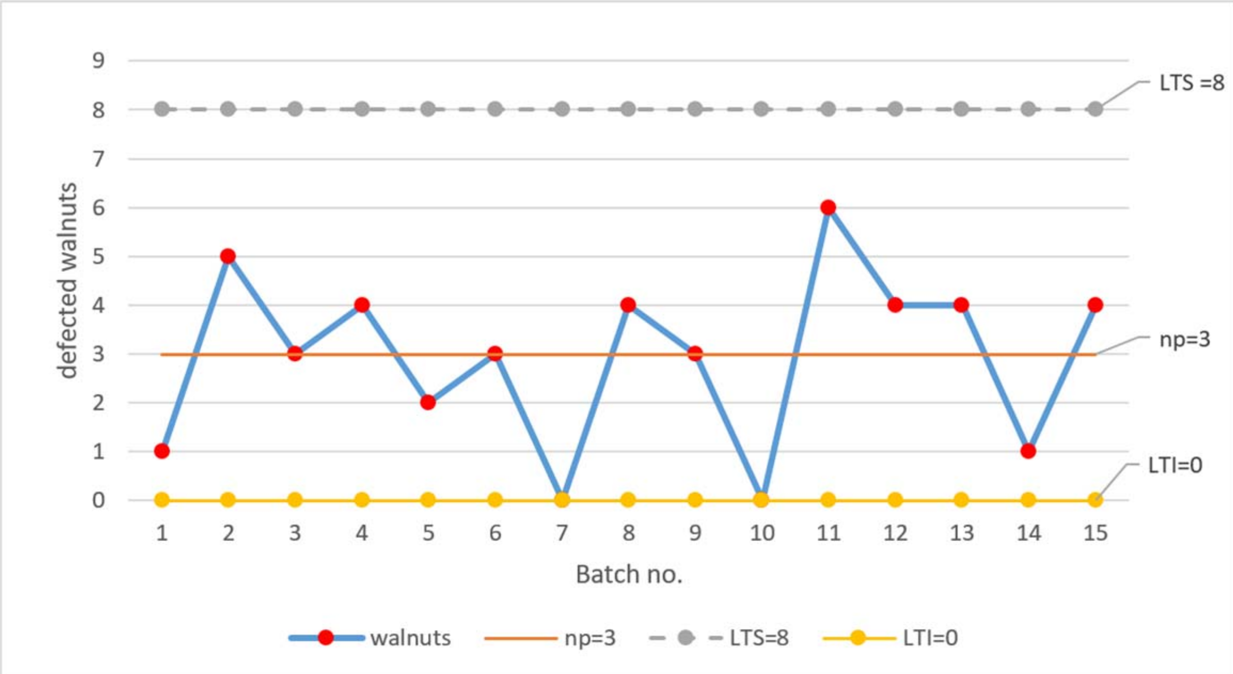

Figure 2. Graphic representation of nP - chart.
Variation of the number of damaged walnuts in the tested lot.

Knowing that walnuts are kept longer, when the intensity of their respiration is reduced, it is advisable to avoid the consequences of respiration-inducing factors: temperature and phytosanitary status [6, 12, 29]. Heat released during storage of horticultural products is proportional to the intensity of metabolic processes, which depend on the ambient temperature. In order to remove this heat, storage facilities must be equipped with ventilation systems.

If respiration heat is not readily operable, temperature rise and rapid depreciation occur [6, 18, 19]. What was also found in our tested walnuts stored at 20± 2^{0}C.

Unsuitable phytosanitary status due to the presence of parasitic microorganisms causes increased respiration [6, 12, 13, 24]. To ensure a normal sweating and respiration process of walnuts it is required that humidity does not exceed 70%. During storage, it is advisable to easily ventilate the deposit for the removal of carbon dioxide, ethylene, heat and excess moisture. It must be taken into account that excess water loss changes the taste and physical attributes of walnut [6, 7, 12].

The experimental study previously conducted has shown that Juglans L. can be infected by fungi, yeasts and bacteria that minimize their quality.

The rate of infection depends on climatic conditions (temperature, humidity), cultivation mode and storage conditions [13, 23, 24].

It has been found that irradiation of walnuts collected from the ground reduces the microbial storage risk by 20-90%. Proper storage ensures the quality and safety of walnuts. It is recommended to prolong the storage and maintain nutritional value of walnuts to carry out their irradiation at 4 kGy dose in 60 minutes[24].

Next, we present in Tables 7 and Figure 3 the results obtained in the testing of the nuts of the Cogalniceanu variety [5].

Table 7.

The frequency of occurrence of defects identified in a batch of nuts harvested in 2016 and kept for 12 months

No.	Defect type	Frequency of occurrence, %	Relative Frequency,%
	External Defects		
1.	Imperfect nuts - cracked, broken, split	0,50	1,32
2.	Adherent Pericarp	0,00	0,00
3.	Excessive external humidity	0,00	0,00
4.	Dark color of the shell	2,50	6,54
	Internal Defects		
5.	Empty Walnuts (without kernel)	1,25	3,27
6.	he presence of moldy kernel	10,50	27,50
7.	The presence of wrinkled kernel (lack of full maturity)	1,75	4,58
8.	The presence of the kernel with a tangled taste	4,00	10,46
9.	The presence of foreign smell	0,50	1,32
10.	Presence of the kernel with excessive humidity	1,00	2,61
11.	The presence of the black / stained kernel	15,60	40,83
12.	Oily appearance of the kernel	**0,00**	**0,00**
13.	The presence of insect attack	**0,60**	**1,57**
	TOTAL	**38,2**	100

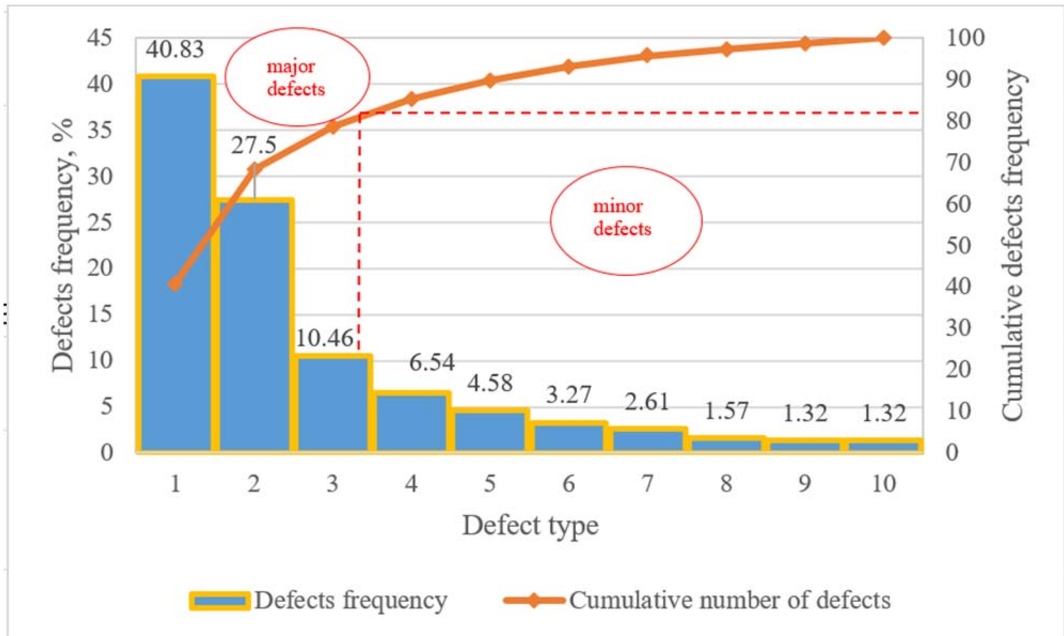

Figure 7. Pareto diagram. The share of defects identified in a walnut batch of 2016 harvest, stored for 12 months. *1 - The presence of the black / stained kernel, 2 - The presence of moldy kernel, 3 - The presence of the kernel with a tangled taste, 4 - Dark color of the shell, 5 - The presence of wrinkled kernel (lack of full maturity), 6 - Empty Walnuts (without kernel), 7 - Presence of the kernel with excessive humidity, 8 - The presence of insect attack, 9 - The presence of foreign smell, 10 - Imperfect nuts - cracked, broken, split.*

The chart indicates that significant defects are the presence of black or stained kernel with a frequency of about 41% of defected walnuts, moldy kernel (27.5%), and rancid walnut kernel (10.45%). Empty walnuts, those with a dark bark, with wet and wrinkled kernel (defects 4-7 in the diagram) are about 15% and the other 6 defects only 5% of the defects [5].

Similar values were also obtained for the batch of nuts harvested in the previous years. Thus, the weight of the first three defects, representing about 23% of the total defects (13), represents about 79% of the damaged walnuts, which corresponds to the principle of functionality of the Pareto diagram. From the data presented, it is obvious that it is necessary to remove the causes that cause their alteration, namely the monitoring of the storage conditions (especially the relative humidity of the air) that would prevent the development of fungi (molds) and the raking and application of technological bleaching treatments of the shell. To store walnuts should be taken into account Code of Practice for the prevention and reduction of aflatoxin contamination in nuts [7].

Conclusion

Bibliographic and experimental study shows that walnuts Juglans regia L. can be infected with fungi, yeasts and bacteria, which minimize their quality. Infection rate depends on climatic parameters (temperature, relative humidity, precipitations and UV irradiation), variety nuts and storage conditions. Good storage practices should be implemented to minimize the levels of insects and fungi in storage facilities.

In order to assess the attractiveness of nuts in the shell, statistical methods based on defect classification (Pareto diagram) were tested and the tolerance limits were determined by the nP chart. It has been found that test methods can be applied to assess the attributive quality of nuts after harvest. According to this upper and lower tolerance limits of defective nuts in the tested lot range from 0 to 8 units. It is possible to improve the quality of walnuts by forming the conditions in which the upper limit must strive to zero to (LTS = 0, the number of defective nuts will be 0)

According to the ***3σ*** conception in a batch of examined walnuts, the content of defective walnuts is determined with the accuracy of 99, 73%, i.e. the potential for error is admitted no more than 0.27%. At the same time the number of walnuts without defects of quality is (100-0,27 = 99,73%).

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