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The design of experiment application (DOE) in the beneficiation of cashew chestnut in northeastern Brazil

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Abstract: Brazil is one of the world´s leaders in the production and processing of cashew chestnut and 100% of these cashew chestnut processing industries are located in the northeastern region of the country. For the maintenance and enlargement of the cashew chestnut market it is necessary to have a guarantee of the product quality by means of controlling the productive process. In this case, the application of DOE (*Design of Experiments*) is suggested in the beneficiation process of the cashew chestnut, notably in the stage of decortication, where the chestnuts are being cut in bands, by a mechanical means. For this process, a fractionated factorial experiment planning was used and evaluated response variable in the experiment was the quality of the almond in the final stage of production, measured by the percentage of whole almonds after the separation from the barks. The chosen process factors were the almonds size, the humidification of the environment, the temperature of the environment before the decorticator and the velocity of the decorticator. At the end of the experiment, it was observed that DOE showed to be an applicable tool that indicates which factors showed to be more influential, as well as, their levels of adjustment. It was observed that the variables related to the size of the almonds, the velocity in decortication are the influential factors of production in this process, apart from a strong noise being identified in this process, observed by the strong variance in the experiment data, especially that of the response variable.

Keywords: Design of Experiments, Fractionated Factorial Planning, Beneficiation of the Cashew Chestnut

1. Introduction

According to [1], Brazil is one of the world´s leaders in the production and processing of cashew chestnut, recognized by the quality of its almonds and reliability of its suppliers. Besides that, 100% of these cashew chestnut processing industries are located in the northeastern region of the country.

The chestnuts without bark, the almonds, are obtained by a mechanical means, but in most of the companies are obtained by manual breaking, and can be sold with or without skin. These almonds have a strong demand in the national and international market, and are very well appreciated internationally.

Besides these almonds, various by-products can be extracted from the cashew chestnut e and can be taken advantage of in diverse industrial fields. [2] Identifies as by-product, for example, the liquid from the bark of cashew chestnut (*LCC*) which is widely used in the chemical industries for the production of plastic materials, isolators and polishes. Besides that, the oil obtained from the chestnut possesses wide applications in the cosmetic industry and the chestnuts with bark can be sold dehydrated, semi-dehydrated or in bulk (without beneficiation). It is still possible to quote the by-product called pie, which is a resulting residue of the crushing and extraction of the oil that presents numerous possibilities of application, with the aim of enriching a great variety of food groups like: panification products, drinks, flours, milks, cereals, snacks, sweets, ice creams, chocolates, biscuits, candies and many others.

Due to the irregular format of the chestnut, the manual process of separating the almonds' bark possesses a big percentage of breaking, reaching approximately 10%. Studies show that on average only 60% of the chestnuts are perfect and the utilization of this quantity as part of the production in the form of by product, is an alternative for taking a better advantage of the prime materials of high value agribusiness [2].

For the maintenance and enlargement of the cashew chestnut market it is necessary to have a guarantee of the product quality by means of controlling the production process, especially for obtaining a high level of the almonds' quality produced. In this sense, the application of DOE (*Design of Experiments*) is suggested, the beneficiation process of the cashew chestnut, in order to achieve a robust productive process and a superior quality of chestnut.

The objective of this work is to describe the application of DOE in a productive stage of the beneficiation process of the cashew chestnut: a stage called decortication, where the chestnuts are being cut in bands, by a mechanical means. The stage determines the quality of the final product, given that only the whole almonds are considered the ones with the best quality.

The concepts of a design project are discussed initially in this article (section 2), that permits the identification of a more adequate model for the set of problems observed in the company; in sequence the company is characterized, as well as its production process (section 3) so that the process characteristics will be well comprehended; afterwards the method utilized in this work is described (section 4) so that the methodological process chosen for the accomplishment of this work can be observed, and finally, the achieved results are discussed (section 5) and the final consideration are explained to the light of production process and the theory of DOE (section 6).

2. Design of Experiments

In the theory of optimization, an experiment is a series of tests in which the input variables are being altered according to a determined rule, in order to identify interference of these variables on the output response [3].

[4] and [5] explain that Design of Experiments- DOE is a systematic method used to investigate the process variables in order to determine which parameters exercise influence on the products quality.

The Design of Experiments, according to [6] starts from the visualization of a productive system like being a set of operations, machines, methods, people and other resources that transform inputs and outputs that can have one or more response variables observed by the means of an experiment. These response variables are the characteristics tested in the experiment, from the change of controllable factors of the process.

To achieve outputs with the planned requirements, it is necessary to have a domination over the controllable factors. Thus, it is necessary to have the knowledge of the influence of the controllable and the uncontrollable factors about the process. Because, for being an influence on the quality and the system productivity, these factors should be adjusted in order to maximize the yielding process.

[6] indicates that to project/control a better functioning of a process it is important to identify the controllable and the uncontrollable variables and to test their influences on the response variable, tested in the experiment. This is guiding principle of experiments.

In this sense the author [7] affirms that the Design of Experiments is a scientific approach of planning e accomplishment of experiments to generate, analyze and interpret the datas in a way that conclusions can be used to design a process more efficient and economic. [8] adds that the DOE involves a set of carefully programmed testes where the operational parameters of the experimental test are personalized, in a way to reduce the time and cost of the experimentation.

Thus, in general, it is concluded that the DOE is a tool used to evaluate the relationship of cause and effect of a determined process by means of series of testes in which intentional changes are accomplished on the input variables, reflecting in identifiable modifications in its response variables [6, 9, 10].

[3] clarifies that the delimitations experiments has its initial basics, in 1920, in the works developed by Ronald Aylmer Fisher, a statistician that created the basics for modern statistics. In sequence, an experimental project of Box and Wilson, in 1951, applied the DOE idea in an industrial environments. In addition to these, the important contribution of Taguchi in 1980, is worth mentioning. Besides to have been very controversial, his contribution had a significant impact in the use of experimental delimitation in the making of management decision, especially in the aspects of quality improvement.

[6] indicates that the way of application of DOE must start with an identification and selection of the factors that can contribute to the variation of the tested response variables. Next, a model that includes the chosen factors must be selected followed by a planned efficient experiment to estimate its effects. Once the experiments have been accomplished the analysis to estimate the effect of the included factors in the model using adequate statistical method, culminating in the interference, interpretation and discussion of the results, recommending improvements, when necessary must proceed.

The ideal adjustment of the process parameters can result in a solution of low cost and the minimization of the occurrence of products out of specification. The statistical analysis of the method are useful in the identification and control of the critical variables, in other words, those that possesses a greater influence on the process, if adjusted inadequately, can cause deviations that affect the quality and efficiency of the product/process [7].

In view of this [11] and [12] indicate that the Design of Experiments is very adequate for studying various process factors and the complexity of their interactions, in order to provide solutions to problems through statistical analysis. Corroborating with this view [13] indicates that by means of Design of Experiments it is possible to evaluate a set of informations that will facilitate decision-making regarding the design and control of the process / product.

Thus, it is affirmed that, the Design of Experiments assists in the determination of the process variables that have more influence on the response variable; in the determination of the adjustment levels of controllable factors so that the variability on the response variable value will be the least, and finally, in the determination of the adjustment levels of controllable factors so that the effect of the controllable factors will be minimized.

For all these possibilities, the DOE is a powerful tool for the improvement of quality and productivity in various productive processes [14, 15], that is why it is widely applied in various industrial contexts, assisting in the determination of parameters and control of process quality.

In this aspect, many examples of the application of DOE in various industrial sectors problems are identified. Examples of works applied in the food industries can be quoted like in the works of [13, 16, 17, 18]; works applied in the pharmaceutical industry and biotechnology like it was demonstrated in the works of [19, 20, 21]; and works in mechanical, metallurgical and chemical processes such as those presented by [22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33].

It is worth noting that the applications of the DOE are not restricted to the manufacturing process problems. [14] presents some benefits of the use of DOE in service organizations based on the response of questionnaires by business representatives. Another example is the work of [34] that evaluated the calculation method of the fixation of tariff for the consumption of electrical energy in order to identify the main elements of tariff cost and their respective impacts. Special technics from the assay of Plackett-Burman were therefore used, technics that identify the variables that had a significant impact on the process.

It is still verified that the application of the DOE in management problems, like those in the work of [35] that presented a method of application of the DOE whose objective was to select production control strategies like kanban and conwip or a hybrid of both.

For it to be applicable in this problem diversity it is necessary to define adequately the characteristics of the experiment and meditate the necessity and difficulty in accomplishing the experiment. About this, [6] emphasizes that as the number of process factors grows linearly, the number of experiments necessary to verify this process grows geometrically. In this way, to experiment a great number of variables can make the accomplishment of an experiment not viable due to the complexity and costs involved.

This fact occurs because to execute a complete planning it is common to test each factor individually while the others remain fixed. According to [36] this type of planning is called full factorial experiment 2k that uses k factors of two levels each, low level and high level. In this type of experiment, a complete replica requires $2 \times 2 \times 2 \times 2 = 2^k$ ...... observations, or 2! that is why it is called full factorial planning.

With an elevated number of factors a full factorial planning can become very onerous, because it requires many experiments [5]. Due to this circumstance the fractional factorial planning was idealized, where it is possible to execute only a subset of the full factorial experiments. This is done by considering mainly the interactions of the main factors, disregarding partly interactions between factors. The factorial notation of this type of fractionated experimental planning is 2^{k-q}.

[3] explains that one fractionated factorial experiment corresponds to half of a complete factorial experiment. This way, a minor quantity of experiments is necessary to evaluate a determined process.

The reduction of the quantity of experiments to be performed is regarded as a very important characteristic for the sake of economizing resources for the accomplishment of experiments. However, it is important to note that in this reduction the identification of the influence of interactions between factors can be lost, giving privilege to the individual influence of independent variables of the experiment

Despite this [36] point that interactions have small values and are dismissed of any practical importance. As in the series expansion of a function, the main effects (i.e., first order) tend to be larger than the interactions of two factors (second order), which in turn are more important than the interaction of three factors, and so on. Thus, the accomplishment of a fractionated factorial experiment is justifiable when the number of factors in the trial is elevated.

Due to these practical questions, in this article it will be assumed that the type of experiment applied in the beneficiation of chestnut business of the Brazilian northeast region will be the fractionated factorial experiment. This way the influence of the main effects will be verified, without considering the interactions between factors.

To understand the phenomenon that will be evaluated by means of the DOE, a description of the company and the productive process is accompanied in a way that is possible to understand the specifications of the process, the effects influencing the process as well as which response variable that is desired to have a higher yield.

3. Case Description

The company where the application of the DOE was made is a solid company that was founded, with a personal capital, in 1979, acting in the market as an exporter of almond and cashew chestnut liquid (LCC). He exports to countries from all continents, including the world's most demanding consumers. He has 800 employees and annual revenues of R $ 20,000,000.00.

Several times awarded for performance and quality, the company uses fully automated processes and maintains internal program of total quality and prevention of environmental pollution, with gas treatment and industrial waste. Usibras possesses an adequate structure that attends the requirements of GMP - Good Manufacturing Practices HACCP - Hazard Analysis and Critical Points of Control and Quality Systems ISO, which make up the Integrated Quality Management System.

An analysis and research laboratory fully computerized gives support to the strict control of quality from the reception of the prime materials to the shipment, thus ensuring a 100% pure product, preserving its visual and nutritional characteristics.

The whole almonds, crushed or in piece, are available in 29 versions, adapted to the most diverse industrial and culinary applications, properly packaged for retail or wholesale. The following are technical informations about the product, its composition and productive process for its beneficiation.

3.1. Description of the Productive Process

The productive process for the beneficiation of the cashew chestnut, for the commercialization of almonds, is accomplished in an automated way, even though in most small businesses there are still manual activities.

The process starts with the arrival of the prime material in raffia sacks and its weighing is carried out on a weighing machine. The Quality Control removes a sample for standard analysis of this material. After the approval of the Quality Control, drying of the chestnut in an open and airy shed is performed the chestnut remains at this location until reaches a humidity of 8% to 10%.Then the chestnuts are stored in burlap sacks in the warehouse of prime material (DPM) for a period of approximately 1 year. This storage prevents the lack of prime material for the process, because cashew is a seasonal product, having strong variations in supply during the year.

The classification of the chestnut is then performed mechanically through cylindrical drums in five granulometric types. At this stage there is already a partial removal of impurities coming from the field (mineral and vegetable waste). After this classification, the washing of the chestnuts is made in a continuous tank with water at room temperature. The objective of this washing is the total removal of mineral and vegetable waste adhered or mixed with the chestnuts. The chestnuts are then humidified in silos with water at room temperature, where thry remains submerged for a period of time about 60 hours. After this period of submersion, the water is removed from the silos and the humid chestnuts stay in rest waiting for the next stage.

In the next stage, the humid chestnuts are cooked in average temperature 190 to 220, avoiding it getting burnt, with its own LCC oil over a period of time not exceeding three minutes of cooking. With this heating, there is the removal of the chestnut's oil and the excess is removed by means of a centrifuge. At the end of this phase, the chestnuts remain in silos for cooling. After cooling the toasted chestnuts advance to the stage called decortication, where the almonds are removed from its bark.

The decortication stage is performed by cutting discs, where the nuts fall and are cut into bands. In this stage the barks are separated from the almonds. The removed barks are separated, because they will be used as fuel for boilers and furnaces. The almonds are directed to the dehydration process in green houses where, through moist air circulation in a temperature of 80 ° C over a period of 12 to 14 hours, the almonds lose moisture and are toasted. After this period of dehydration, it is necessary that the almonds rest for 10 to 12 hours.

Soon after this rest, it is the removal of the almonds' skin by the process of "despeliculamento". This removal is made mechanically by means of compressed air. After this removal the almonds pass through selectors photo machines, conveyors and separators (pneumatic) for mechanical, electronic and manual cleaning. The whole almonds that still have small amounts of skins are scraped, this way keeping the almonds on a level of high quality. This is most desired in the market.

Finally the almonds are classified visually among 1st, 2nd and 3rd quality, pieces, mash, band, etc.., where part of this classification is taken for grating and the other part is taken for revision. The rest goes directly for packaging. The almonds are packaged through a vacuum system with a CO_2 injection giving a total guarantee of quality and absence of possible infestations in the process.

This productive process is described graphically on figure 01 diagram presented below.

The points of control (PC) and the points of critical control (PCC) are in blue and red, respectively.

One of the controlling points in the process of chestnuts beneficiation is the decortication process, which is the phase that consist of the separation of the bark and the almond. In this process the chestnuts go on a vibrating conveyor up to a cooler, remaining there for an average of 2 hours until the beginning of the decortication process or the breaking of the chestnuts, which is performed through centrifugation, casting them against a metallic surface.

This stage is important for the determination of the quality of the final product, because the whole almonds (without breakings) and without skin are classified as the product of 1st quality, which in this case can be sold with the highest price in the market and also in the international market.

Due to this, the application of the DOE was chosen so as to reduce the rate of breakings and keeping the final product on a superior quality.

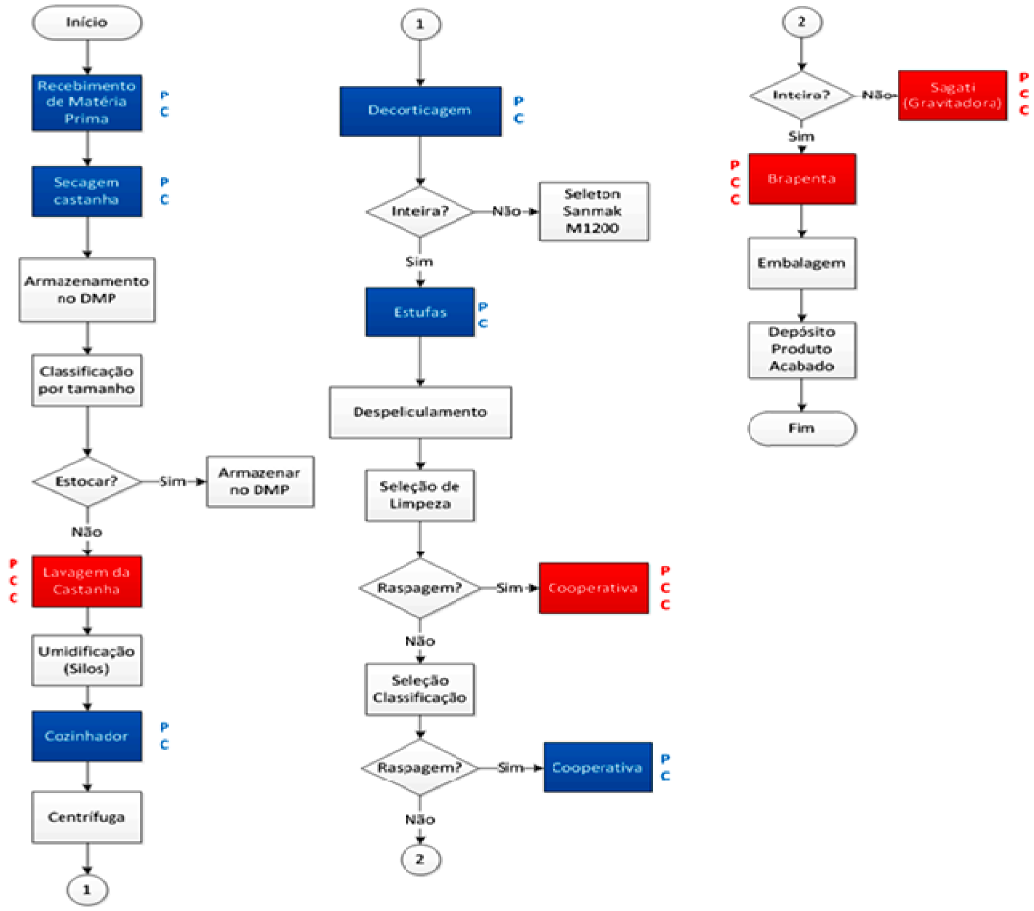

Figure 01. *Diagram of the productive process of the improvement of the cashew chestnut.*

4. The Experiment Description

At first visits to companies were made so as to examine the possibility of application of the DOE. Unstructured interviews were therefore carried out, that allowed the outlining of the experiment project with the management of the company, where the choice of the stage called decortication was made for the application of the design of experiment described in this work.

For this stage, the response variable was defined as being the percentage of breakings of the almonds. Thus, in this case, the interpretation of the response variable is; the lower the percentage of broken almonds the better.

After the determination of the stage where the design of experiment will be applied, just like the response variable was defined, the process factors to be tested were determined. The determination of these factors was oriented by the process management and by perception, the factors that will exert the most influence on the decortication process were given.

The following process factors were defined: the size of the almond, humidification of the environment, room temperature before decorticator, velocity of the decorticator. For each of these factors a level zone that should orient the design of experiment was determined. The levels of each experiment are described on table 01.

Table 01. *Factors and tested levels in experiment.*

Factors	Lowlevel (-)	High level (+)
A – size of the almond (mm)	18 to 21	23 to 28
B - humidification of the environment (%)	< 10,7	≥ 10,7
C – Temperature before decorticator (°C)	<33	≥ 33
D – Velocity of the decorticator (rpm)	<45	≥45

After the definition of the response variable of the factors and process levels that will be tested, the experiment project, to be executed, was outlined. For this design of experiment, the fractionated factorial with eight types of experiment was chosen.

The choice of the fractionated factorial was made, because it sought in principle, the determination of the individual factor influence on the response variable, without being objective, in this moment verifies the interrelationship between the factors, which would be possible by the application of a complete factorial experiment, for example.

The accomplishment of eight experiment was projected. For this, it was necessary to do a confounding between the levels of the factors A and B for the generation of the levels of factor D. the characteristics of the levels of all the factors that should orient the accomplishment of the eight experiment are presented in Table 02.

It is possible to observe that the eight experiments to be accomplished should follow the levels as is shown in this Table 2. Thus, for example, the experiment N°1 should be accomplished with calibrated factors with the following levels; Size of the almond (low), humidification of the environment (low), temperature before decorticator (low) and velocity of decorticator (high).

Following the orientations presented in table 02, the execution of the experiments and accompaniment of the response variable, follows. This permits the identification of which of the factors is most influent and to which level the process should be calibrated. The description of the attained result with the application of experiment study is presented in section 5.

Table 02. *Levels of the projected fractionated factorial.*

Experiment	Factors			
	A	B	C	D (A*B)
1	-	-	-	+
2	+	-	-	-
3	-	+	-	-
4	+	+	-	+
5	-	-	+	+
6	+	-	+	-
7	-	+	+	-
8	+	+	+	+

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5. Discussion of the Results

Five replicas were made for each of the eight experiment. After the collection of experimental datas, the average and the variance of the response variable were calculated, this is the percentage of broken almonds at the end of decortication. The table 03 presents a set of collected datas.

Table 03. *Datas of the accomplished experiment.*

N° of	Factors				Repetitions % of breakings	
exper.	A	B	C	D (A*B)	μ	Si²
1	-	-	-	+	18,49	0,429
2	+	-	-	-	19,77	22,87
3	-	+	-	-	21,71	15,11
4	+	+	-	+	18,57	33,23
5	-	-	+	+	15,28	26,22
6	+	-	+	-	23,74	6,50
7	-	+	+	-	17,77	25,78
8	+	+	+	+	18,53	3,66

For these presented datas on table 03, the rates of effect for each of the factors were calculated. The values of effects for each factor were 1,84, -0,18, -0,81 e -3,03, respectively for the factors of A, B, C, and D. analyzing the individual effects factors, it can be seen that the factors A and D appear to be more significant in absolute values.

For a more consistent analysis, a comparison of the values calculated effects of individual factors with the critical value of the Student t curve. Proceeding with the calculation of the "t" value calculated for each factor, the values of 0,45; 0,043; 0,197 and 0,74 were obtained for the calculated t of factors A, B, C and D respectively.

Comparing these values with the tabled critical "t" of 1,69, considering a reliability of 90%, it is seen that non of the factors is in a critical zone. Besides this, the A and D factors , that corresponds to the size of the almonds (mm) and the velocity of the decorticator (rpm) are identified, respectively, showing that they can be more expressive in comparation to the other factors and, therefore, deserves attention and adjustment to attain a better quality of the process.

Thus, it can be affirmed that the size of the almond (factor A) and velocity of the decorticator (factor B) have a great influence to the breaking rate of the almonds. The small sizes of the almonds (18 to 21mm) and the high velocity of the decorticator (>45 rpm), therefore, would be the most adequate configuration for the process of decortication, because, it would be the adjustment of the factors considered to be ideal for the maximum range of the quality of this process.

If the values of table 03 are observed, it will be seen that the experiments 1 and 5, are the ones that present the best performance, in other words, are the ones that possess the best average of response variable. Thus are the experiments that obtained the lowest rate of breakings of the almonds after the decortication process.

It is worth noting that the size of the almond depends on the characteristics of the prime material provided by the rural producers of the region, whom are the main suppliers to the company. As the company in question acquires inputs from multiple suppliers, this causes the chestnuts to have a broad range of sizes, making it difficult for the company to control this specific factor.

Thus The characteristics of the almonds that will be processed are intrinsically related to the availability of stocks. So it can be said in a way that the factor A is not fully controllable by administrators.

Given this fact, it would be interesting to analyze the ideal levels of the factors for the size of each almond (18, 21, 23, 25 and 28 mm) in order to determine with more specificity the most adequate adjustment for this factor. In this work, only the analysis for the size of 21 mm (table 04) will be presented. But the presented calculations can be extrapolated for the other dimensions.

For the accomplishment of this experiment a complete factorial experiment with three replicas for each experiment was idealized. Based on the datas of this new experiment, the effects of the factors B, C and D, that were 0,20, -1,70, respectively, can be calculated.

Table 04. *Experiment data considering the adjustment for Factor A (21 mm).*

N° of exper	Factors			Repetitions % of breakings	
	A	B	C	µ	Si²
1	-	-	-	17,10	6,71
2	+	-	-	17,86	24,10
3	-	+	-	17,35	5,66
4	+	+	-	17,13	12,63
5	-	-	+	18,67	0,72
6	+	-	+	16,75	4,70
7	-	+	+	14,52	8,93
8	+	+	+	16,70	7,02

As occurred in the previous experiment analysis, it is seen that none of the factors can be considered very influential, making an individual and comparative analysis. Making an analysis, according to the Student curve, it is seen that the temperature before the decorticator, factor C, shows to be the most influential in relation to others.

By this statement, observing the data in Table 4, it is identified that the response variable, rate of breakings of almonds in percentage, has the best result when the temperature was calibrated to the high level, > 33 ° C.

Thus, considering the possibility of controlling the size of the almond in 21 mm, the second experiment indicates that the temperature before the decorticator exerts moderate influence on the rate of broken almonds in the process.

However, it is worth noting that in both experiments, there are no factors that can be considered very influential. But, it was found that some factors exert an influence on the response variable, and can therefore be calibrated to provide a superior quality process.

This fact can be explained by the large variance observed in the process. This can be observed in the datas of the accomplished experiment and presented in the tables 3 and 4. This great variance in the data of the experiments can be explained by the presence of "noise" that were not identified during this accomplished experiment project.

Thus, by the low influence that was observed from the tested factors on the process, it can be inferred that such noise can exert an intense influence on the response variable. Therefore, it is suggested to identify such noises using the model of Taguchi for the experiments project for future works.

6. Final Considerations

The objective of this work was to develop a design of experiment for the process of beneficiation of chestnuts in a company of the Northeast of Brazil, especially the process of decortication where the separation of the barks and the almonds occurs.

It was noticed that, the DOE identified that some factors can be considered less influential in this process, because an elevated variance in the experiment datas that suggests that too many noise interfere in the process, was observed. Besides the great variance of the response variable, the main factors and their respective levels for the process were outlined.

It is important to pay a special attention to the “noises” in this case, because they can have a significant influence and, besides that, proceed with tests to determine the best arrangement of the factors for the various sizes of almonds because this factor is not entirely controllable by the company.

A justification for the great influence of noise in this process is the fact that this design of experiments are being accomplished in an industrial environment, and not in a laboratory environment where the levels and adjustments are more easily controlled and the influence of noise is lower.

In general, the accomplishment an experiment design in an industrial environment has proven to be a very difficult task, because the company has its production demands during the execution of the experiment and is not always possible to calibrate the process in order to collect the datas according to the instruction of the designed experiment.

Besides that, in an industrial environment, there is a lot of possibility of noise that can interfere with this process, from variables like environmental comfort variables up to organizational characteristics can interfere with a process where the level of mechanization is not absolute.

Nevertheless, the application of the Taguchi method, as a tool for the design of experiments so as to identify these noises and their influence in this process, is suggested.

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