HACCP System Review and Application of Continuous Improvement Strategies to Reduce Critical Product Defects in Food Production Lines

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Abstract: The following project was developed in a bakery industry, with the main focus on the review and improvement of the implemented HACCP System.

A careful examination and on-site confirmation of the HACCP documentation was carried out. This documentation identifies the hazards, evaluates the risks and respective implemented preventive measures that allow to eliminate and reduce the probability of the hazard to acceptable levels. Many critical control points were identified and new critical control limits were implemented for the metal detector.

The second half of the work was carried out in the framework of improving the quality of the bread production line, in order to decrease the appearance of holes in the bread crump, a recurring defect in the whole grain breads, namely the Pão 0% Açucares brand (0% Sugars Bread). In this sense, many possible causes that may lead to the existence of this defect were identified, having in mind the whole manufacturing process and also the raw materials used. Correlations between the process parameters and the appearance of holes in the bread crump were analyzed, using the data retrieved.

During this project, some basic process parameters were reset and corrective actions were implemented. However, these efforts did not prove effective in the reduction of the defect's appearance, although some of the possible causes presented before were ruled out.

Keywords: Bakery, Food Safety, HACCP, Quality Control, Continuous Improvement

1. Introduction

1.1. Quality in Food Industry

In the food industry, the main objective of the quality systems is to ensure the development of food according to the quality and safety requirements imposed by legislation, by customers and consumers.

Food quality and safety are concepts that encompass different realities. Quality is the set of characteristics food requires, while food safety is exclusively linked to the risks that may be harmful to consumer health. Thus the HACCP (Hazard Analysis and Critical Control Points) is usually part of the quality management system of a food company. [1] [2]

In order to control the quality of food and the process to obtain a product with the expected characteristics, the focus must be on continuous improvement of its processes and products. Thus, this work aims at the continuous optimization of production processes, seeking to reduce its variability and minimize the occurrence of nonconformities in the products in terms of their specifications.

2. Hazard Analysis and Critical Control Points (HACCP)

2.1. Overview

2.1.1. Definition

HACCP is a food safety control methodology for identifying hazards along the entire food chain and define the preventive measures for their control.

This methodology is based on prevention to ensure that the food produced, stored and transported is safe for consumers. The HACCP system is thus seen as a systematic and structured analysis tool of the hazards of food processing, fully documented and verifiable. [3]

2.1.2. Concept origins

The HACCP concept was developed in the 60s, by the company Pillsbury Corporation, in collaboration with the US Army and NASA laboratories. This partnership had the goal of stablishing ways to produce fully safe food for the US Space Program. One of NASA's concerns was to ensure the safety of the food that would be consumed by astronauts, without having to destroy the products after being analyzed. This led the American scientists and engineers to develop a tool that could prevent the incidence of hazards and ensure safety of the edible products. The HACCP system was then officially presented in 1971 at the National Conference on Food Protection. [4]

In 1985, the NAS (National Academy of Science) recommended the widespread use of the system, have then been introduced in the European Union in 1993 by Directive 43/93 of the Council of 14 June. In Portugal, the policy was implemented in Decree-Law No. 67/98 of 18 March 1998. [5]

Recently the European Directive 43/93 has been replaced by the new Directive 852/2004 and in September 2005 the International Organization for Standardization (ISO) established the ISO 22000 which defines the requirements for the implementation of Food Safety Management Systems, according to the HACCP methodology. The implementation of this standard allows the definition of a Food Safety Management System, which enables the compliance with legal requirements, in particular Regulation (EC) No 852/2004, as well as the recognition of the entity as a "Certified Company". [6]

2.1.3. HACCP System advantages

The HACCP system has benefits for companies and consumers, in that:

- It is applied throughout the food chain, controlling food in all its stages;
- Increases food security levels in the factory;
- Promotes the Philosophy of Prevention, instead of final product based control, reducing waste;
- Reinforces the company's image and consumer confidence;
- Directs the human and material resources to the key points of the process;
- Provides documents that detail the control of the process;
- Highlights compliance with specifications and codes of good practice
- Provides the means to prevent errors in food safety management that would otherwise jeopardize the company's survival;
- Facilitates trade opportunities within and outside the European Union;
- Reinforces compliance with national and Communitarian legislation. [6] [7]

2.1.4. The Principles

The HACCP system is based on seven fundamental principles:

Principle 1 - Conduct a Hazard Analysis
Principle 2 - Identify the Critical Control Points
Principle 3 - Establish Critical Limits
Principle 4 - Monitor CCP
Principle 5 - Establish Corrective Action
Principle 6 - Verification
Principle 7 - Recordkeeping

2.1.5. HACCP Methodology

The 7 basic principles are implemented into the system through the 14 steps: [1]

I. Scope definition

Define which product or process will be the scope of the HACCP approach and what types of hazards will be considered. Here is also determined at which process steps the study begins and ends.

II. Assemble HACCP team

The HACCP team is responsible for the preparation, implementation and maintenance of HACCP System in the company. It must be selected to ensure its multidisciplinary.

III. Describe product

Elaborate marketed product technical data sheets in order to well characterize them.

IV. Identify intended use

The potential consumers of the product are identified and also studied their intended use of the product.

V. Construct flow diagram

The diagram must detail all the process steps, since the reception of the raw materials until the distribution of the final product.

VI. On-site confirmation of flow diagram

Comprises in comparing the flow diagram with the actual manufacturing that it represents. This is mandatory for the validation of the entire process.

VII. List all potential hazards associated with each step, conduct a hazard analysis, and consider any measures to control identified hazards (Principle 1)

All reasonably expected hazards, which their elimination or reduction to acceptable levels is mandatory to produce a safe edible product, must be identified in each step of the process.

Afterwards, a risk analysis must be carried out for each of the hazard identified. This analysis is defined by the probability of occurrence of the hazard versus its severity when it occurs, as well as the already existent or to-be-implemented preventive measures that allow to eliminate or reduce the occurrence of the hazard to acceptable levels.

VIII. Determine Critical Control Points (Principle 2)

The HACCP team must identify the process points in which its control is critical (CCP), namely the points to be monitored in order to eliminate or reduce the occurrence of a hazard and where the control failure leads to an unacceptable risk without the possibility of subsequent correction. For this identification, the CCP decision tree is recommended by the Codex Alimentarius.

IX. Establish critical limits for each CCP (Principle 3)

For each established CCP, the parameter to control must be specified as well as its respective critical limit. Respecting this limit is essential to ensure its effective control. These critical limits will have to be defined on a scientific basis or by consulting available legislation.

X. Establish a monitoring system for each CCP (Principle 4)

Close monitoring can detect situations outside the established limits for each CCP. Monitoring procedures should allow the timely detection of loss of control of a CCP, allowing the control to be restored before being necessary to segregate or destroy product.

XI. Establish corrective actions (Principle 5)

A corrective action plan has to describe the procedures to take place when a CCP is out of its limit.

XII. Establish verification procedures (Principle 6)

The verification procedures allow to determine whether the HACCP plan is being correctly implemented, whether it is appropriate to the actual product/process and whether it is effective in hazard control. It must also ensure that the CCPs, the monitoring processes and the corrective actions are correctly executed. The frequency of verification must be sufficient so as to validate the HACCP System and must be done each time there are adjustments to the process, machinery, equipment or raw materials.

XIII. Establish Documentation and Record Keeping (Principle 7)

An organized log and archive system is essential for the effective implementation of HACCP. The HACCP system documents may include:

- A description of the HACCP system;
- The data and any information used to perform the analysis of hazards;
- The proceedings / conclusions of the HACCP team meetings;
- The logs of identification of the PCCs and their respective monitoring;
- The procedures of monitoring and their logs;
- Archives comprising possible deviations from the PCC limits and the respective corrective actions taken to mitigate such deviations;
- Audit reports to the HACCP System;
- HACCP System review reports.

XIV. HACCP plan review

The HACCP system reviews must be held in between scheduled fixed time intervals and each time a change to the product, process or raw material occurs, leading to a constant need to adapt the system to the reality of the company.

2.1.6. Prerequisites programs

The ability to implement the HACCP System is tightly dependent on the level of implementation of the prerequisite programs (PRPs). These allow prevent eliminate and reduce the hazards that may contaminate the food during or after its production.

These prerequisites control the hazards associated with the surrounding environment of the edible product production process, while the HACCP System controls the hazards related to the production process itself. In general the following HACCP prerequisites are considered:

- Construction and layout of building
- Layout of premises and workspace
- Equipment suitability, cleaning and maintenance
- Cleaning program
- Pest control
- Utilities (air, water, energy)
- Waste disposal
- Management of purchased material
- Materials exclusively for contact with edible products;
- Health and Personal Care;
- Training of workers. [8] [9]

2.2. HACCP System Review

A review of the HACCP System implemented for all production lines in a bakery plant was carried out in the first stage of the developed work. The work was performed giving special emphasis on careful examining the documentation that comprises the hazard analysis and how the preventive measures are established.

Each production line of the factory has its own HACCP manual. Each of the HACCP plan comprises all the steps ranging from the raw material reception, up to the storage of the manufactured edible products in the distribution centers.

2.2.1. Product description

Each one of the products has its own technical datasheet with the following items which are periodically updated:

- Name and description of the product;
- Countries where it is marketed and distribution method;
- Important features of the product;
- Ingredients;
- Allergens;
- Net weight;
- Type of packaging;
- Process conditions;
- Product validity and storage conditions;
- Physico-chemical and microbiological specifications of the product:
- Specifications of raw materials and packaging material;
- Label text.

The products marketed are intended for a market composed of people of all ages, from children to adults, excluding people sensitive to the allergens mentioned in the product description. All products are to be directly consumed without any previous treatment.

2.2.2. Operational phases and flow diagram

The flow diagrams were reviewed on-site.

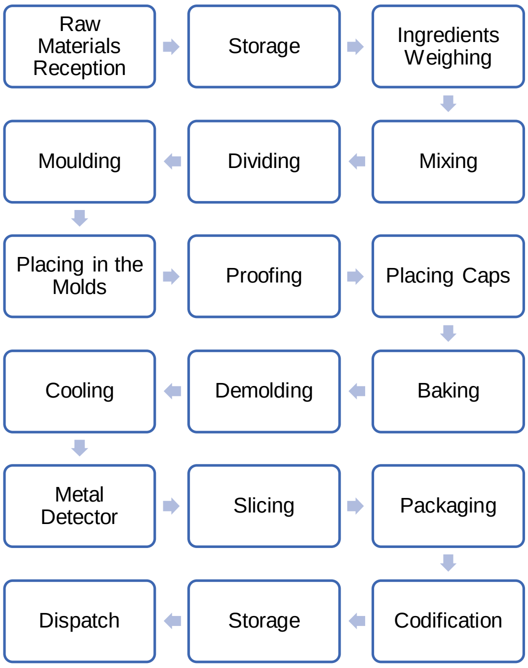


Figure 1 – Bread production line flow diagram

2.2.3. Hazard analysis and preventive measures

In this phase the possible hazards that can occur in each step of the process are identified. The respective preventive measures are also presented along with the risk analysis for each of the considered hazard.

The potential hazards that may lead to the product contamination can be sorted in three categories: chemical, physical and biological hazards.

Chemical Hazards: Chemical contaminants may be contained in the raw material used, such as heavy metals, pesticide residues, melamine, dioxins, PCBs, benzopyrenes, mycotoxins and bacterial toxins such as S. aureus. These hazards are controlled by the selection and qualification of suppliers, and analyzing the material's certificate of compliance and analysis reports. [10] [11]

Other chemical contaminations may occur during production, ranging from contamination by lubricants, refrigerants, dirt and detergents in the equipment. These hazards are controlled by establishing a cleaning plan and training the workers.

Physical Hazards: These are associated with the presence of any physical material that, when introduced into food, can cause damage to the consumer health. These materials can be categorized into metallic (bolts, turnings, etc.) and non-metallic objects (wooden chips, fragments of packaging materials, acrylic materials and rigid plastic fragments). Metallic objects differ from their non-metallic counterparts by being able to be detected with a metal detector. The occurrence of this hazard is limited by having proper worker training at the good practice level and verification inventories of rigid plastics existent in the manufacturing area

Biological and Microbiological Hazards: In terms of Biological hazards, it is considered contamination by insects and their fragments, rodents, among others. The factory has implemented a pest control program and random checks are carried out to the flour type raw materials, at the time of reception.

Microbiological contamination hazards are mostly by pathogenic microorganisms (Salmonella, Staphylococcus aureus, etc.), fungi and molds. This hazard is usually associated with failures in good hygiene and manufacturing practices, raw materials contaminated or no compliance of hygiene rules.

Risk analysis

For each one of the potential hazards, the probability (P) of occurrence as well as its severity (G) were reevaluated. Based on literature, the recent historical record of the company and the experience of the HACCP team members, each hazard was classified for its probability and severity, considering the following tables:

Table 1 - Severity Index.

Value	Classification	Description
1	Low	Do not cause damage or disease.
2	Moderate	It may cause small damage or diseases that does not need medical attention.
3	High	Probably produce injury or illness requiring medical assistance, but without hospitalization.
4	Very High	Probably produce injury or illnesses that require hospitalization and can even cause death.

Table 2 - Probability index.

Value	Classification	Description
1	Impossible	Never occurred and the possibility to occur is almost "zero".
2	Unlikely	The frequency of occurrence is < 1 time/year.
3	Likely	The frequency of occurrence is 1 a 5 times/year.
4	Most likely	The frequency of occurrence is > 5 times/year.

Using Table 1, Table 2 and Equation 1 the Risk Index (RI) was computed. This determines the risk level of each hazard with Table 3.

$$RI = P \times G \quad \text{Equation 1}$$

Table 3 – Risk index determination and control measures.

RI	Risk Level	Requirements
$RI \leq 3$	Null	PRPs may be sufficient as long as operational and regularly checked
$4 \leq RI \leq 6$	Low	PRPs may be sufficient as long as operational and regularly checked
$7 \leq RI \leq 8$	Medium	Requires specific control measures (CCP decision tree)
$9 \leq RI \leq 15$	High	Requires specific control measures (CCP decision tree)
$RI = 16$	Very High	Requires specific control measures (CCP decision tree)

2.2.4. CCP decision tree

Using the CCP decision tree, the process phases that lead to a bigger risk were determined. These phases are in fact CCPs. Hazards with a low or none risk level were not considered in this evaluation. These hazards are controlled by the prerequisites program. In the bread production line manual, the baking phase and the metal detector were identified as CCPs.

2.2.5. Critical limits, monitoring systems and corrective actions for each CCP

For each CCP found, the critical control limits were specified, considering technical information or in existing legislation. In this work, many of the critical limits were review.

Metal detector: The correct functioning of the metal detector is checked as a control measure. This is done by passing in test patterns containing a metal sphere, which must be rejected by the metal detector. This ensures that all metallic foreign elements which diameter is equal or greater than the respective metal sphere will be rejected. The diameter of these spheres of different types of metals are detectability limits.

Metals can be classified for this purpose in three main categories: ferrous metals, non-ferrous and stainless steel. There is a pattern for each of the three types of metals, ensuing that the detector is testes in all different materials.

Firstly the detection band was optimized, so these could operate with more sensitivity, without being affected by interference from the actual product itself has some electrical conductivity [12]. This way it was possible to reduce the control limits for metal detectability in all production lines.

Baking / frying: The potential hazard in this step of the process is the possible survival of microorganisms due to insufficient cooking. In order to control this CCP, it is necessary to control the temperature in the core of the baked product as it leaves the oven. The critical control limit was established based on a previous study. In this work it was verified that the limits are adequate and that the parameter is under control.

2.2.6. Conclusion and Recommendations

The use of preventive tools is the best way to ensure food safety for the consumer, being the HACCP control system recognized as the most effective for the production of food. However, the HACCP system is dependent on the implementation of prerequisites to be effective, implying the involvement of all stakeholders in the food chain.

The work performed was an important part in the review of HACCP system, especially with the update and improvement of the HACCP manual of all production lines and its verification on site. In the course of this review, were also detected improvement opportunities at certain stages of the factory. This work contributed to the renewal of the company's food safety certification, or the preparation for obtaining that certification for the production lines that are not yet certified.

3. Project of Continuous improvement of a Product

3.1. Overview

The study developed in this second part focuses on improving the quality of products produced in the bread production line, and in particular the bread "*0% Açucares*" (0% Sugars). The most recurrent defect on whole grain bread 0% Sugars is the presence of holes in the crump.

In the following chapters the role of each ingredient used in the production of bread and the successive line production steps is described, giving emphasis to the physicochemical changes arising at each stage.

3.1.1. Raw materials

Flour: The two most important classes of flour proteins in the formation of bread are gliadin and glutenin. When the flour is mixed with water and kneaded, these gluten proteins form a viscoelastic matrix with the ability to grant extensibility and elasticity to the dough, and also making it impermeable to CO_2 produced by the yeast. [13] [14]

Yeast: Yeast function is to convert the dough free sugars into ethanol and CO_2, by alcoholic fermentation. The CO_2 retained by the dough will allow the mass to gain volume.

Water: Water hydrates the flour proteins which makes the formation of the gluten network possible.

Salt: In addition to enhance the flavor of the bread and bolster its conservation, salt strengthens the links between the gluten chains, making them more cohesive. It also has the function of regulating the performance of the yeast in the dough, which favorably influences the structure of the crumb. [15]

Sugar: The sugar found in the dough serves as a substrate for yeast to carry out the fermentation. Sugars turn the bread crust more dark by caramelization of the surface. They also act as a softener by absorbing water and attenuating the development of gluten. This prevents too much gluten being developed which would make the dough too stiff and hard. [16] [15]

Fats: Fats influence the dough softness. It turns the gluten network more elastic, which improves the retention of the carbonic gas released during fermentation. [16]

Additives: In modern baking additives are usually added for correcting wheat flour deficiencies and allowing a certain tolerance in the process, which facilitates the standardization of the quality of the final products. Emulsifiers, oxidizing and reducing agents are examples of food additives used in bakery.

3.1.2. Industrial process of bakery

The bread production line of the factory is exclusively dedicated to sliced bread. Different forms and compositions of sliced bread are produced in the line, using white or whole grain flours.

Mixing: After dosing the ingredients, the mixing phase promotes the formation of new connections between the glutenin and gliadin, forming this way gluten. The mixing also allows the infiltration of air which will occupy gas cores inside the bread dough. The dough fermentation begins immediately in the mixing step. [17] [18]

Dividing: After the mixing phase, the dough is taken to the volumetric divider where it is cut into pieces.

Molding: In the molding step, the dough balls pass through rollers that pinch the dough to a disk-shaped. In this way, a part of gas present in the mass is expelled, thus obtaining a more even distribution of the alveoli. The formation step begins by the folding of the dough and it subsequently passes by the molder, squeezing it and ensuring the desired length of bar shaped dough.

Proofing: This is the stage where proofing of the dough bars is held. The dough is carried in molds without cover and it occurs at controlled temperature and moisture. It is in this stage that is produced more CO_2. The gas produced diffuses into the air bubbles previously created in the mixing step, and is retained by the gluten structure. In this way, the elasticity and extensibility of the gluten network will allow that the dough to stretch under the produced CO_2 pressure. This originates an increase in the volume of the dough. [19]

Baking: The covered molds are fed to the oven. During the initial temperature increase CO_2 gas is produced, leading to a slight volume gain. At 50-60 °C, the yeast is destroyed by heat and ceases its activity. Between 60 °C and 80 °C, starch gelatinization and the denaturation/coagulation of the protein network occurs. This structure solidifies, making up the crump of the bread and the space occupied by the gas turn into the numerous alveolus of the crump. At about 80 °C, the gas can pass through the meshes of the protein network. Caramelization and Maillards reactions occur on the surface of the dough leading to browning and the formation of crust. [20] [17]

Cooling: After leaving the mold, the loaves undergo a cooling step in a chamber with moist air circulation. Once cooled, the loaves can be sliced and packaged.

3.2. Study Case

It is considered a hole in a slide of bread, the holes that are visible from both sides of the slide with a diameter equal or greater than 1 cm. A loaf of sliced bread is classified with this defect if at least a hole is found in at least one of its slices.

The following work focused exclusively in finding the possible causes for the appearance of holes in the "*Pão Integral 0% Açucares*" (0% Sugars Whole grain bread) and subsequently presenting improvement proposals to reduce this defect. However, this study is valid for the remaining whole grain bread produced in the factory which the appearance of holes in the crump is also recurring.

3.2.1. Identification of possible causes

The production process, as the amount and type of ingredients used, affect the development of the honeycomb structure of the loaf. The use of whole meal in the bread 0% Sugars and other whole grain breads hinders the baking process. The insoluble fibers of whole grain flour interfere with the formation of gluten, weakening it. The retention of gases is impaired and the bread volume tend to decrease

However, when inspecting the finished 0% Sugars breads, it was found that the slices were not very dense and often had a crumb structure with large alveoli. Sometimes it was found breads with holes that formed along the length of the bread. In the mixing step it was also observed, that the mass presented with a soft consistency and very "sticky" after the mixing step.

3.2.1.1. Possible causes related with ingredients

Additives: The cumulative effect of wheat gluten and additives which promote the retention of CO_2 in the mass can contribute to the appearance of holes.

Flour time to mature: Higher flour storage time improves their properties leading to the formation of a more cohesive gluten network, without tearing under the pressure of CO_2 retained during the proofing step. In this particular case, the time between the manufacture of flour and its use may not be sufficient for an optimal improvement of their properties. [21]

Variation of flour characteristics: It was found that the characteristics of the received flour (P, L, W) are very variable and it is difficult to make settings on the production line to compensate for that.

These parameters define whether a given type of flour is ideal to produce the desired type of bread.

Yeast activity: The yeast activity varies greatly from batch to batch, making it difficult to adjust to the dosage. The yeast can also activate too early, leading to an early strong production of CO_2.

Yeast mass: The amount of yeast may be used in excess, resulting in greater CO_2 production.

Amount of water: The fact that the mass has its "sticky" nature may originate from inadequate mixing time according to the amount of water added. It can also originate due to the fact that the dough is already over hydrated. [22]

3.2.1.2. Possible causes related with process steps

Order of addition of ingredients: The compressed yeast was placed at the beginning, staying on the bottom of the mixing container, remaining in contact with the liquids. This dissolves the yeast more quickly, leading to an early onset of fermentation.

Dough mixing time: Since the mass of the 0% Sugars have a "sticky" nature, a pertinent hypothesis is that the mixing time may not be optimized.

Too short mixing time leads to the formation of an undeveloped protein network and in case of a prolonged mixing, the gluten network starts ripping, losing the ability to retain water through the network.

Dough temperature in the mixing tub: The temperature of the dough tends to increase during the mixing phase. To control this parameter water is replaced for a portion of ice. The dough temperature at the end of the mixing is crucial so that the yeast does not produce too much CO_2 ahead of time. For dough of 0% Sugars, it was found that this temperature is on average greater than the expected.

Sprinkling flour in the mixing tub: Due to the consistency of the mass under study, the sprinkled flour on the tub edge portion before the end of mixing is higher than normal, which may contribute to the appearance of holes.

Weight of the cut dough: There is some variability in the weight of the dough cut by the divider. The dough of with lower weights may lead to the formation of less dense breads, possibly with bigger alveoli in the crump.

Temperature in the mixing room: In high temperature days, especially in the summer, the mixing room temperature (mixing until the proving step) is greater than supposed since a deficient functioning of the air conditioning system. In this case more ice should be added to the dough in order to prevent a premature fermentation.

Laminator and formation machine adjustments: The appearance of holes in the bar alongside its length suggests that the tightness of the laminator's cylinders or the formation machine belt are not suitable for this type of dough. The distribution of the alveoli of the dough is insufficient in lamination step or the formation machine tightening may be insufficient. In this case, there may be a limitation of the equipment.

Fermentation: When consulting the control charts for temperature and humidity, it was found that the process was not controlled and the temperature and humidity of the chamber are sometimes out of specification for this product.

Temperature at the start of baking: If the CO_2 production or expansion of the gas is too abrupt in the first cooking phase, it may lead to disruptions of structure that sustains the dough.

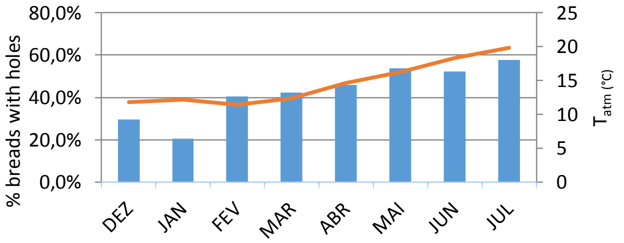
3.2.2. Data mining and analysis

The parameters that can influence the appearance of this defect to examine were selected, in order to determine if there is any correlation. In this sense, each of the factors listed in Table 4 were compared with the percentage of non-compliant breads through scatter plots, to check if there is any relationship. Of these factors, the one who cannot be directly or indirectly regulated by the operator is the room temperature of (T_{Room}).

Table 4 – Relevant control variables for the study

Production step	Control Variable	Symbol
Ingredients Weighing	Mass of yeast	$M_{Yeast.}$
	Mass of water	M_{water}
Mixing	Mixing time	T_{Mixing}
	Dough temperature	T_{Dough}
Proofing	Fermentation room temperature	$T_{Ferm.}$
	Fermentation room humidity	H_{Ferm}
	Fermentation time	$t_{Ferm.}$
Baking	Temperature of the oven	$T_{1st\ s.oven}$
Other	Temperature in the mixing room	T_{room}

In the case of T_{Dough}, T_{Ferm}, T_{oven} and H_{Ferm}, the average value of temperatures and moisture listed in the respective control register was used.



It was researched whether the data in each scatter plot fit linearly through a linear regression obtained by least squares method. Thus, for each variable, it was intended to get the following line:

$$Y = a + b\ X_i \qquad \textit{Equation 2}$$

Wherein each Y value are the percentage of examined breads with holes in a given production and Xi are the values of the respective productions of each variables under study presented in Table 4.

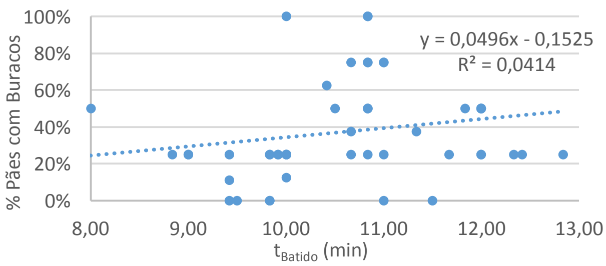


Figure 2 – Mixing time and percentage of bread with holes.

By analyzing the resulting graphs, it appears that the process variables does not fit to the linear model of Equation 2, it is concluded that there is not any linear relationship between the factors analyzed and the holes' appearance. As an example is presented the scatter plot obtained for the mixing time (Figure 2). The R^2 values are presented in Table 5.

Table 5 – Coefficient of determination (R^2) obtained from linear regression between each factor and the percentage of examined breads with holes.

Factor	R^2
$M_{Yeast.}$	0,238
M_{water}	0,052
T_{Mixing}	0,041
T_{Dough}	0,010
T_{Ferm}	0,074
H_{Ferm}	0,046
t_{Ferm}	0,082
T_{oven}	0,182
T_{Room}	0,050

As can be seen, R^2 values are close to zero indicating that the data do not fit the linear model, suggesting that the relationship between the factors and the percentage of bread with holes is inconclusive.

Note that the sample of breads per production is very low, which can lead to excessive statistical errors due to non-representative sample.

Of the percentages of rolls with holes inspected during each month, it was observed that there is a seasonal trend. That is, the months of greatest heat tend to lead to higher percentage of defect appearance (Figure 3). Accordingly, high temperatures in the factory may have some relevance in the incidence of defects whether by changes in raw materials, whether in different stages of the production process.

Figure 3 – Percentage of examined breads with holes and monthly average temperature of the atmosphere in Sintra (T_{atm}). [23]

The existence of some correlation between the weight of the breads and the hole occurrence was also studied. Assuming that each hole has the shape of a circle, the sum of the surface areas of the holes of each bread (S) was computed, being this value null when there is no hole in the bread. With these values and with the weight of the respective breads, a scatter diagram was plotted (Figure 4), although proving once more that these two factors also not correlated ($R^2 = 0.0016$).

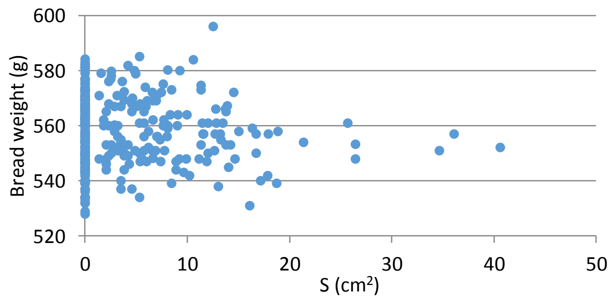


Figure 4 – Sum of the area of all holes of a bread (S) and its weight

3.2.3. *Reset of the basic operational conditions, corrective actions and results*

Some operational conditions were reset to their basics, along with corrective actions that were executed:

- Training refreshment of the workers was held with the objective to help them reacquire the operational processes, in particular that the temperature of the dough has to be within the specifications. With the temperature under the specifications, it was not observed any reduction in the appearance of holes in the 0% Sugars bread.
- The mechanical apparatus that comprises the divider machine was replaced by the maintenance team. The air that defaulted the dough's fall has stopped building up on the bottom of the dough,. With this corrective action, it was expected a reduction in the percentage of inspected bread with holes, but that was not verified.
- The divisor software was updated, allowing it to correctly and automatically measure the weight of the cut balls of dough. This improvement led to less variability in the mass of the dough balls.
- It was redefined that the yeast needs to be added to the mixture in last place, staying now on top of the other ingredients, instead of in the bottom.

3.2.4. *Conclusions and recommendations*

At the moment, it could not be found out what are the causes for the recurrent appearance of holes in the whole grain bread, particularly the 0% Sugars bread. However, a seasonal trend was discovered with higher incidence of the defect in the months of greater heat. Some factors have been eliminated. Other possible causes were pointed out and can be explored in future work. A list of proposals that can lead to improvements follows:

- Control charts of the process of the proofing stage need to be reviewed and possibly the specifications of temperature and moisture of the 0% Sugars need to be adjusted.
- Mixing time of the 0% Sugars dough and the respective specification need to be reviewed.
- Refine the amount of yeast in the specification.
- The height of the upper conveyor belt adjust system needs to be facilitated, so it can be easily tweaked by the workers. Markers in the adjuster can be drawn so the workers know how to adjust without variability.
- Elaboration of a study project about the laminator, the formation machine and their adjustments..
- Evaluation during an additional time period what influence maybe the outside temperature has on the appearance of holes.

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