Implementation of an automatic control system on a roaster of peruvian andes grains

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Abstract. This paper presents the results of the automation of a roaster of grains grown in the Peruvian Andes. The research work consisted in developing an automatic control system for the temperature and speed of rotation of the drum of a gas roaster machine with mechanical-electrical control. The new system is based on a PLC with a proportional control algorithm for temperature and an open loop for drum rotation, which allows the grain temperature to develop, in time, the predefined curves for its 3 types: corn, broad beans and soybeans. The cultivation of these in the various microclimates along the Andes Mountains gives them unique characteristics that condition the proper roasting to the operator's experience. To that end, a matrix was developed with parameters whose values were determined by tests conducted by expert operators in manual roasting. The experimental results showed that the roasted beans reached the desired quality characteristics such as humidity, color, aroma and flavor, as well as a decrease in the duration of the process and in fuel consumption, as well as the reduction of waste for over-roasting.

1. Introduction
The roasting process of Andean grains comprises a series of stages, each of which is defined by certain values of temperature, time and humidity level of the grain similar to the roasting process of coffee beans [1]. The automation of this process requires the control of certain variables, which depending on the characteristic of each grain will determine the adjustment of certain parameters for proper roasting. Because the response of the temperature of the grains to an increase in the reference signal is predominantly slow, it is feasible to use a proportional controller, which can reach the desired temperature in a suitable time, and maintain it with an error in state stable relatively small. The tests carried out with the objective of establishing the roasting parameters allowed to determine a roasting curve for each type of grain, being able to establish a thermal path line through which the grain passes during its roasting, being that between each reference signal adjusted by stage there is a transition stage that coincides with the curve that follows the grain temperature during the rise time, allowing a gradual increase in grain temperature. Following the roasting process stages on coffee beans tested on [1]; three stages were defined for the roasting of the Andean grains, after the preheating, a temperature uniformization stage is started for the grains recently admitted to the drum, in a second stage the temperature is increased to start the grain drying, and a final stage that seeks to active aromatic components in a phenomenon similar to the caramelization of sugars, which is characterized by a roasting of the external part of the grain in order to refine its aroma and color. The tests for the determination of the roasting curves for each grain allowed to establish empirically the proportionality constant of the control system implemented in a semi-industrial roaster of mechanical-electrical control, on which the various elements were adapted, such as: a control panel, a PLC with analog inputs and outputs, temperature sensors, gas pressure sensors, proportional valves for LPG, and a frequency converter, in addition to modifications in the mechanical and electrical elements in order to
obtain a roaster whose automatic operation is programmable by the user. As a result, all these modifications have made it possible to standardize the roasting of the grains, reduce the processing times and the over-roasting that impaired the nutritional potential of the grain.

2. Automation of the grain roaster

In this chapter is explained the full operation of the roaster, the description of the temperature control system, the speed control system and the user interface for configuration and monitoring the process.

2.1. Operation of the roaster

The roaster shown in figure 1 consists of a horizontal cylindrical drum with capacity for 44 pounds of grains, two burners located under the drum that divides it into two zones of temperature control, an electric motor to rotate the drum on its own axis and a manual mechanism to tilt the drum after the grains are roasted. The roaster must be preheated before placing the grains in the drum. Then, the grains are added to the rotating drum and roasted. Finally, the roasted grains are removed from the drum due to the manual action of the mechanism that allows the drum to tilt. The roasting temperature, the roasting time and the centrifuge speed depend on the type of grain.

![Figure 1. Main view of automatic roaster.](image)

2.2. Temperature control system

In processes that involve temperature, it is important to use some type of control to reach a desired or defined temperature. For example, in the work carried out by Schiller, S [2], they compare the ON / OFF control and the proportional control to determine which is more efficient with the actuator being a pump, the plant is a solar collector and the sensor is a thermostat. They conclude that in most cases, the proportional control gives a greater efficiency to reach the desired temperature.

A more specific case, in which it is required to control the temperature in a meat oven, is found in the study conducted by Mielche, M [3]. In it, 4 different types of control are applied on the temperature variable with some modifications in the curves of the sensed value. The objective of its control system is to obtain the quality parameters without prolonging the heating time too long. The best type of control assigned is the so-called TDR, since it offers a smoother heat treatment in a shorter cooking time. TDR is based on the direct assignment of the supplied voltage in a short period of time and then a proportional control is applied.

Finally, in an experiment conducted by Chhaiya, Deep & Kathiriya, Rohit [4], a proportional temperature control was applied to a rotary roaster of food or products based on rice. After the implementation of its design, it is possible to study the accuracy of the type of control applied.

The roaster of the present study has two thermocouples in the zones of the drum to measure the temperature and contains a pair of solenoid valves to control the flow of gas in the burners. The sensors measure the temperature of the two zones in the drum in real time and send the information to the PLC. The scientific articles studied for temperature control and specifically those related to food treatment are taken into account. For this reason, a proportional control is applied.
2.3. Speed control system

It has been investigated how speed affects machines that use a rotating drum mechanism for the treatment of food. For example, the work presented by Kaensup, W [5] consists of a chili-drying machine that uses a speed variator in the rotating drum, they conclude that the variation is crucial to eliminate the effects in the dead zones, that is, in periods of time where the process starts or ends. In addition, the speed varies according to different types of foods that are used. The speed of rotation is controlled by an electronic speed variator.

Another work presented by M. Delele [6] indicates that the speed of rotation of the drum affects the operation of a rotary drum in two ways. On the one hand, it affects the production capacity, and, on the other hand, it is an important factor when determining the effect of the dead zone in a similar way to the article presented previously [5]. Additionally, in the study by A. Olasumboye [7] where a rotating drum mechanism is also used, it uses the method of varying the speed of the drum and uses an OMRON frequency variator.

Based on these mentioned investigations, the use of a frequency inverter was implemented to modify the speed of the spin drum according to the type and quantity of grain that is being roasted. The roaster has a gear motor of 1 HP and a speed of output of 60 rpm. In addition, it has a mechanical transmission by gears and chain. The pulleys have a number of teeth in a ratio of approximately 1: 2 because the speed delivered by the electric motor must be reduced and the toaster must rotate at a maximum speed of 29 rpm. A frequency variator of the SIEMENS brand is used to control the speed system, which is selected according to the power of the motor and the load it moves.

2.4. Interface for configuration and monitoring

The system controller is an S7-1200 PLC from the SIEMENS brand, it is used to control the temperature and speed variables by using sensors and actuators distributed along the roaster. The operating interface between the user and the system is a 7” touch screen from the SIEMENS brand. The communication with the controller is done through an RJ45 cable and programmed in the STEP 7 TIA PORTAL software. The interface is configured so that, when the process is started, the user can decide whether to perform an automatic or manual roasting as shown in figure 2.

![Figure 2. Image of the selection screen for weight and type of grain for automatic roasting.](image)

3. The process of roasting Andean grains

In order to meet the desirable characteristics, a grain roasted for the production of pre-cooked or instant food requires certain physical and chemical modifications.

3.1. Chemical changes

There is a complex chemical process that triggers multiple effects on the chemical structure of a grain. This is known as the Maillard reaction [8].

3.1.1. Maillard reaction. The implemented toasting system maintains a temperature between 210ºC and 235ºC for a period of 12 minutes; these values depend on the type of grain. After that lapse of time, the Maillard reaction occurs, which can be perceived by the appearance of dark spots and cracks in the
surface of the grain (see figure 3). This process is characteristic of toasting processes with high carbohydrate and protein content [8] and subjected to temperatures above 120ºC.

![Figure 3](image)

**Figure 3.** Maillard reaction in corn, broad bean, and soybeans respectively.

3.1.2. *Activation of aromatic components.* The chemical processes between the proteins and the sugars triggered at the beginning of the Maillard reaction release aromatic elements [9], which are accentuated in the last stage of roasting. In it, it continues with the reduction of moisture and water activity in the grain, which will allow the flours of these grains to be stable under environmental conditions.

3.2. *Physical changes*

The characteristics of the grains grown in the Andes are very diverse in terms of size, shape and level of humidity, because they are collected from different areas of cultivation, with diverse climatic conditions and sun dried by hand.

3.2.1. *Drying process by moisture reduction.* The heat applied on the grains releases water particles in the form of vapor. In turn, the decomposition and evaporation of certain organic acids cause the texture of the grain to change, towards a slightly rough surface and with cracks due to the rupture of the cell walls of the grain during the escape of the water molecules [8].

3.2.2. *Modification of mass and density.* Water vapor and carbon dioxide, as a consequence of the roasting process, generate high pressures inside the grains, which modifies their cellular structure, increasing the volume from the decrease in the thickness of the walls of the cells [8]. This is noticeable mainly in the grains of corn, a little less in the wheat and in the broad bean, with the consequent loss of mass by drying and reduction of the density after the increase in volume. In the measurements made, a reduction of the mass in the grain of the order of 7% is observed for the case of corn, with an average volume increase of 9%, while the broad beans lose 15% of mass and soybeans 3% after the roasting process.

3.2.3. *Color variation.* During the Maillard reaction, there is a change in color: the roasted grain acquires a brown color [10], although in the case of soybean there is not much difference. We can appreciate in figure 4, the change of color that the corn grains experience during toasting, with the presence of slightly darker areas due to the irregularity of the grain.

![Figure 4](image)

**Figure 4.** Darkening of corn color during automatic roasting.

Both the reduction of humidity and the low water activity present in the Andean grains after roasting facilitate the post-roasting processes, such as grinding.

4. *Roasting matrix*
It is known that, during roasting, the grains undergo various physical and chemical changes. The way in which these affect the food characteristics of the grain —i.e. nutritional value, flavour, aroma and color— will depend on the time of exposure to heat and the temperature at which they will be subjected. Considering these factors, a matrix was designed with parameters of speed, temperature and time, from which certain rules were established for the behaviour of the roaster in each of the three stages defined in the process of automatic roasting: a first stage for homogenize the temperature of the grains after loading, a second stage characterized by the loss of moisture, and the third stage where the Maillard reaction occurs.

5. Results
The automatic grain control system allowed the levels of humidity and acidity in the grains to be reduced after roasting. This last factor reduces the feeling of bitterness in food. The moisture reduction, the water activity (Aw) and the level of acidity are shown in table 1.

| Grains    | Moisture Before | Moisture After | Aw Before | Aw After | Titratable acidity Before | Titratable acidity After |
|-----------|-----------------|----------------|-----------|----------|---------------------------|--------------------------|
| Corn      | 15.32           | 8.55           | 0.65      | 0.38     | 0.24                      | 0.13                     |
| Soybean   | 11.25           | 7.63           | 0.66      | 0.46     | 0.62                      | 0.37                     |
| Broad bean| 14.33           | 3.27           | 0.63      | 0.20     | 0.63                      | 0.40                     |

The new values of moisture and acidity were reached after roasting through the stages defined according to the values shown in table 2, where the system's operating configuration is shown.

| Operational Parameters | Broad bean | Soybean | Corn |
|------------------------|------------|---------|------|
| Speed of rotation (RPM)| 26         | 25      | 26   |
| Equipment load (Kg/batch) | 20        | 20      | 20   |
| Maximum Temperature (°C) | Stage 1   | 180     | 180  | 170 |
|                         | Stage 2   | 235     | 210  | 230 |
|                         | Stage 3   | 245     | 240  | 240 |
| Time (minutes)          | 29         | 15      | 18   |

Two zones were determined in the drum, in order to standardize the roasting of the grains, due to the disturbance that is generated in the door of grain entry. To compensate for this distortion, two loops of proportional control were implemented on the temperature of the roasting drum, one for each zone. In a stage prior to the entry of the grains, the preheating of the drum is performed whose maximum temperature will depend on the type of grain. As shown in figure 5, 6 and 7, the path of the temperature curves of the grains from the measurements of the sensors in zone 1 (light blue) and in zone 2 (orange).
6. Conclusions
The selection of sensors and control elements was made based on the operating conditions of the roaster. In the particular case of temperature sensors, they must work non-invasively on the grains, to ensure safety and not generate disturbances on the process. The roasting of grains, after applying a temperature control, is shown uniform for the 44 lb. avoiding internal burn and better use of the material entered. The configuration parameters of the equipment for roasting broad beans, soybeans and corn allowed to obtain satisfactory and standardized results from the physical aspect (uniformity of color) and chemicals (% moisture, water activity and % acidity), getting grains or roasted seeds suitable for the following transformation processes. It was found that the temperature during the roasting of the grains and seeds had an error in stable state of less than 2%, that is to say in general rules it was kept within a range of ± 5 °C in relation to the programmed temperature. Three stages of roasting were defined: a first short-term stage that allows the cold entering grains to acquire a uniform temperature; a second stage of greater duration, which favors the loss of moisture of the grain, as well as its internal cooking (the temperature curve must be gradually rising to avoid burning the external part of the grain); and finally a third stage in which the change of color and the aroma of the roasted grain are manifested. The development of this machine allows to improve the efficiency in the roasting process of the grains grown in the Andes. In Peru, this productive sector is mostly occupied by small companies that would be favored by increasing their competitiveness in the Andean grain derivatives market.

7. References
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