Monitoring and characterization of process production losses to support production planning and cost establishment.

Bernardo Matias [a]

[a] *Instituto Superior Técnico, Universidade de Lisboa* December, 2015

Abstract

Nutriceal Foods, S.A. is a baby food production company, which has several production lines, such as the drum dryers line. The present work aimed at monitoring and characterizing drum dryer process, which is the process that represents the main cause of production losses.

A predicting model was developed and applied. This model is used to predict losses in the production process based on the historical data from previous productions. The model was designed to predict the final product that will be attained at the end of a production, and it is versatile with values of moisture content in raw materials and final product, so that it can be specified by the user for each product. The model also provides a prediction of the output of the recipe which can help predicting the production duration that can be used in the equipment production planning.

The model is able to give a prediction of the process loss with an average deviation of 2.4%. This tool was developed in Excel and allows the losses prediction for new recipes, and not exclusively to recipes previously produced in the factory. This fact comes as an improvement when compared with the former method of prediction used in the company.

Several comparisons were also made between the developed model, the previous prediction method and the linear correlations attained with the software Minitab.

Process losses were also correlated with the drum dryers' characteristics and with the composition of the recipes.

Keywords: Baby food; Drum dryer; Losses; Model; Recipes.

1. Introduction

The aim of this work was to monitorize and characterize the losses on the drum dryer production line, and with this data, be able do predict the total losses of the process.

To fully understand the process, a state of the art study on the drum drying process was made.

In the factory there are three drum dryer production lines. Two of which operate with a pair of drum dryers and another with only one.

A predicting model was developed and applied to the drum dryer process. This model was designed to give the user the final product prediction according to the raw materials input. The model can also be used based on diferent moisture contents of raw material or final product, if it is specified by the user.

With this prediction it is possible to have a rigorous planning of a given recipe. These predictions are particular important for new recipes as it allows, without any production, having an estimated loss if a recipe is interesting from the financial point of view.

2. Drum Dryers

The drum dryers are widely used in drying of viscous solutions and pastes, since it's one of the more efficient methods available [1]. The viscous slurry or paste is mechanically spread by the spreading action of two counter-rotating drums into a thin sheet that adheres on the hotter drum in single drum dryers or split sheets on both hot cylinders in double drum dryers. The satured steam passes inside the drum dryers where it condensates due to the heat exchange with the drum wall.

There are many types of drum dryers available, and they are classified according to the number and configuration of the steam-heated drums and the pressure of the atmosphere around the drying sheet.

The production lines that have two drum dryers each, operates with “atmospheric single drum dryers”, as shown in Figure 1.

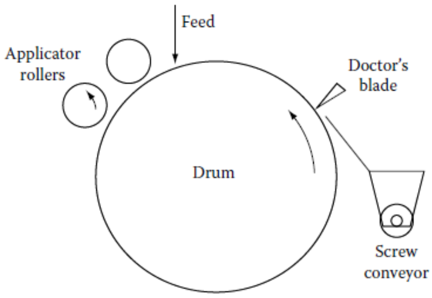

Figure 1 - Single drum dryer with applicator roller feed *[2]*.

The drum dryer, with a single drum, is fed from the top where the paste is spread by the applicator rollers and the end of the drying process is scraped by the doctor’s blade. The equipments that fit this description are the drum dryers 1 to 4, where drum dryer 1 is smaller then the rest.

The remaing production line operates with only a drum dryer that is illustrated in the Figure 2.

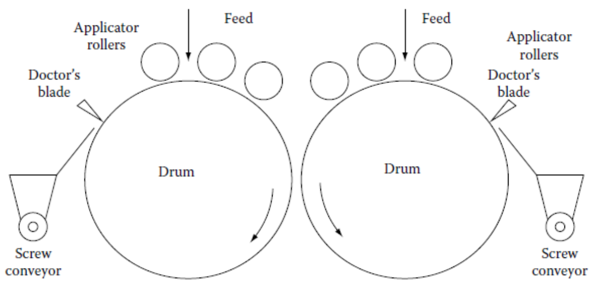

Figure 2 - Twin drum dryer with applicator roller feeds *[2]*.

Like the single drum dryers, the drum dryer 5 is fed from the top and the product is spread by the applicator rollers. The counter-rotation of the drums spread the slurry or paste into two thin sheets on both drums that consequently dry conductively.

3. Drying Process

The process of drying the product in thin sheets can be divided in different zones as shown in Figure 3 and Figure 4.

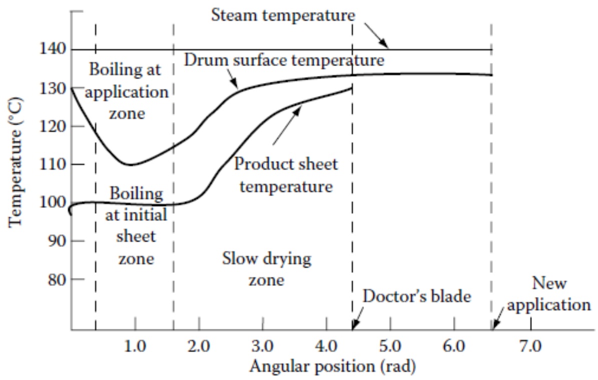

Figure 3 - Temperature profile of the drum dryer *[2]*.

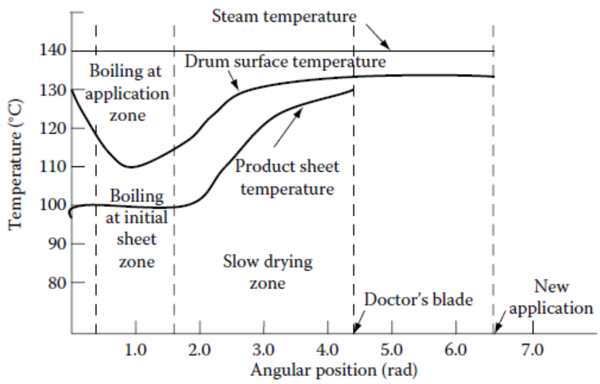

Figure 4 - Moisture content profile of the drum dryer *[2]*.

Initial Application Zone

The sudden exposure of the liquid feed to the high temperature and intense heat flux on the drum surface at the application zone causes it to immediately heat up and boil. Most of the free moisture is evaporated during this initial boiling of the feed.

Initial Sheet Zone

The drying regime of the thin sheet of liquid or paste on the drum surface is dictated by the high temperature and the large heat flux supplied by condensing steam inside the drum.

Moisture transport in the sheet is predominantly driven by the large temperature gradient and the subsequently large pressure gradient within the sheet. Excess surface water in the wet sheet flashes or boils off the sheet and the temperature of the drum surface continue to fall whereas the product sheet temperature remains constant.

Slow Drying Zone

The sheet becomes quite dry very quickly and the temperature of the drum surface as well as that of the sheet start to rise, until the product is scrapped of the surface of the drum.

Reheating Zone

The temperature of the drum surface continues to rise until it reaches the initial temperature so it can receive product again.

4. The Model

Data from previous productions and collected during this work was used to develop the predicting. The collected information represents a total of 169 productions of the recipes of Nutriceal Foods, S.A. The gathered data, in terms of recipes, has the distribution shown on Figure 5.This recipes were organized in groups according to their composition and, in the final division, their main ingredient. (Figure 6)

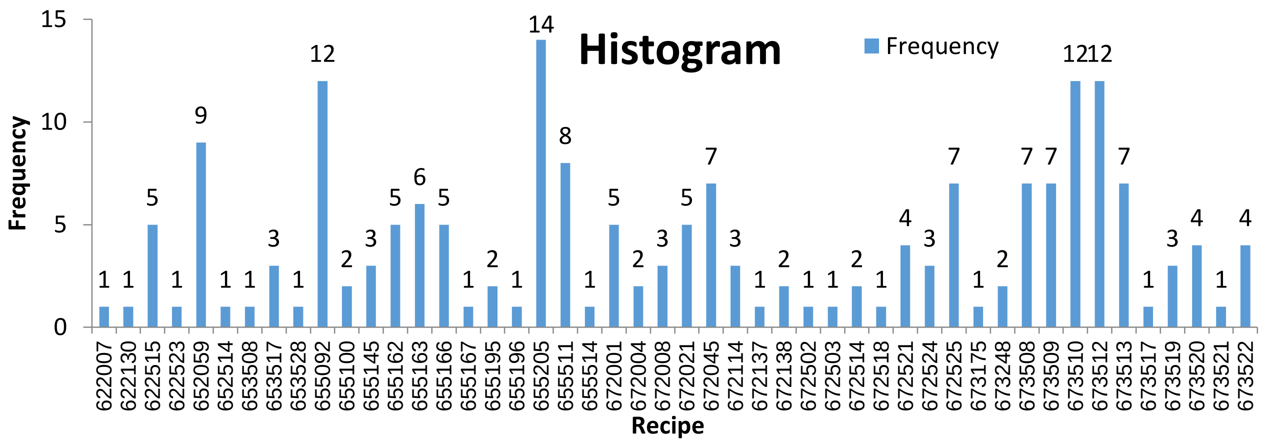

Figure 5 - Recipes frequency on the collected data.

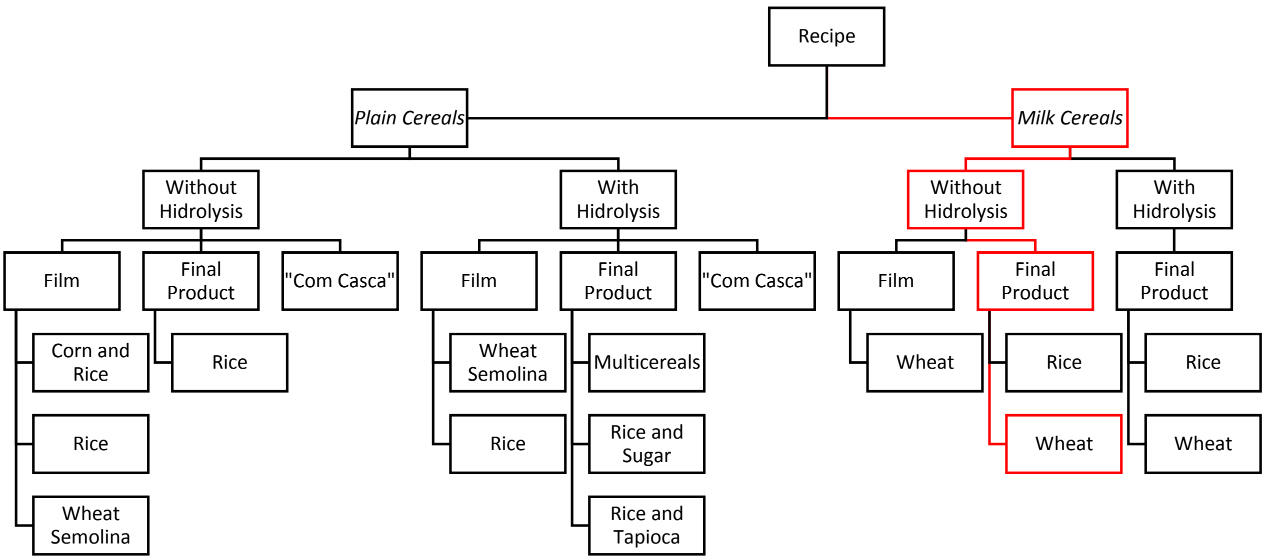

Figure 6 - Recipes classification.

The film is a product that is still going to another step of the process and final product describes product that is ready to go to the packing step.

The recipes groups have different representativity in the historical data, as listed in Table 1.

Table 1 - Number of entries in the collected data.

Plain Cereals	WO/Hidrolysis	Film	Corn and Rice	17
			Rice	14
			Wheat Semolina	9
		Final Product	Rice	13
		With Husk		9
	W/Hidrolysis	Film	Wheat Semolina	1
			Rice	2
		Final Product	Multicereals	29
			Rice and Sugar	3
			Rice and Tapioca	1
		With Husk		3
Milk Cereals	WO/ Hidrolysis	Film	Wheat	8
		Final Product	Rice	19
			Wheat	28
	W/ Hidrolysis	Final Product	Rice	4
			Wheat	9

To build the model, each group was considered individually using the same method, but from here forward only one group will be shown, as na example

The process losses were divided in two types, Variable Losses and Fixed Losses. The first one occurs during the production and operation of the equipments which depend on production run. The second type is independent of the production run because they only occur during the start and stop of the production.

The following fixed losses, for the recipe group here analysed in more detail, and the anomalous points representing operating problems removed.

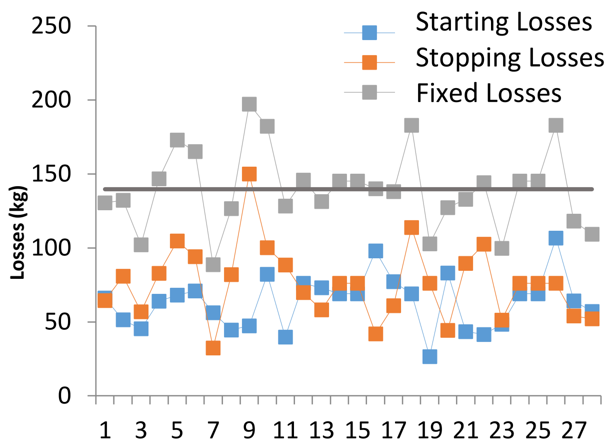

Figure 7 - Fixed losses (dry basis) of the recipe group.

There are two ways of getting the variable losses. The more correct one, which is to sum of all the losses measured in the process, has lack of data (only 18 of the 169 productions have the full information on variable losses). Therefore, the variable losses were caculated from the difference between the raw material that enters the process and the final product. This approach has disadvantages, but when compared with the lack of information of the other approach, this one seems more realistic. Since these losses depend on the production run, they are defined as a percentage of the entering raw material. These losses are illustrated in Figure 8.

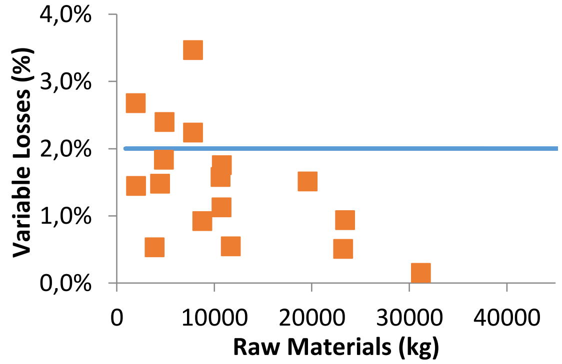

Figure 8 - Variable losses (dry basis) for the recipe group.

With the mean value for each type of losses, an equation, to obtain the prediction for the total losses, can built. For this recipe group the equation is:

$$\text{Total Losses}_{DB}(\text{kg}) = 140 + \text{RM}_{DB} \times 2\% \qquad \text{Eq. 1}$$

where DB stands for dry basis and RM for raw materials.

The model gives the user an estimate of the final product, in wet basis, using Eq. 2 and the result from the Eq. 1.

$$\text{Final product}_{WB}\ (\text{kg}) = \frac{\text{RM}_{WB} \times (100\% - \%\text{H}_{RM}) - \text{TL}_{WB}}{100\% - \%\text{H}_{Product}} \qquad \text{Eq. 2}$$

where WB stands for wet basis and TL for total losses.

Table 2 presents the average values and the respective error corresponding to the fixed losses and to the percentage of variable losses.

Table 2 - Losses for all recipe groups and respective error.

				Fixed Losses	Variable Losses
				kg	%
Plain Cereals	WO/ Hidrolysis	Film	Corn and rice	113 ± 54	2,2% ± 1,8%
			Rice	151 ± 21	3,1% ± 1,4%
			Wheat Semolina	89 ± 26	1,1% ± 1,1%
		Final Product	Rice	85 ± 35	1,5% ± 0,9%
		With Husk		144 ± 59	2,1% ± 1,3%
	W/ Hidrolysis	Final Product	Multicereals	120 ± 50	1,3% ± 0,7%
			Rice and Sugar	165 ± 55	2,2% ± 2,2%
Milk Cereals	WO/ Hidrolysis	Film	Wheat	148 ± 48	2,2% ± 0,9%
		Final Product	Rice	149 ± 48	2,4% ± 1,1%
			Wheat	132 ± 24	2,3% ± 1,9%
	W/ Hidrolysis	Final Product	Rice	178 ± 15	1,2% ± 1,2%
			Wheat	104 ± 47	5% ± 3,7%

Besides giving a prediction for the final product from the amount of raw materials, the develop model also provides a prediction of the output for the production. For the recipe group in analysis, the collect values are shown in the Figure 8.

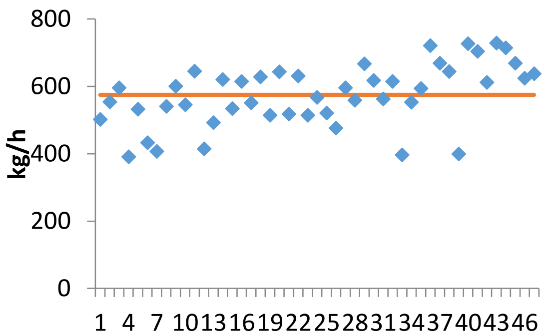

Figure 9 - Output for the recipe group in analisys.

If the two set of drum dryers are taken in consideration independently, the set with the drum dryers 1+2 gives a smaller output due to the smaller dimension of drum dryer 1. Due to this difference, the model allows the user choosing the set of drum dryers to use.

The fixed and variable losses, moisture content of raw materials and final product, the global output and output of each set of drum dryers are all listed in a secondary table, used to obtain the final results.

These values represent the average values obtained for each recipe group and are used when other values are not specified. When the parameters are specified, the model replaces the mean values with these new ones and makes the predictions with these new inputs.

This prediction model was developed in excel, and the interface was made to be as simple and intuitive as possible, so the input values and the given results are in wet basis just like it is weighed in the production line. The interface of the model is shown on Table 3, where the yellow cells represent the production parameters the user can optionally use.

To check the model, a verification test was made, and for a few weeks, all data were collected to compare the real production with the prediction from the model. The total losses percentage per production, was calculated and it is shown in Figure 10.

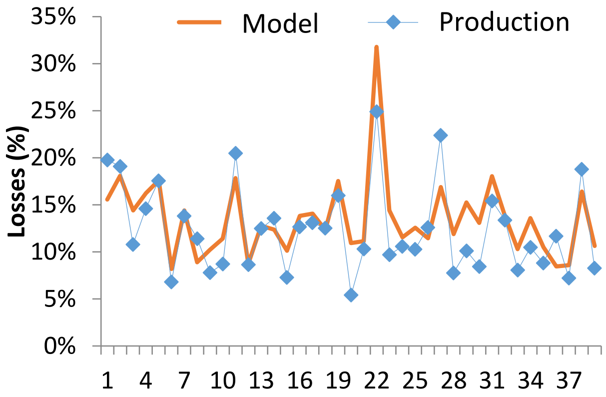

Figure 10 - Percentagem of total losses fro week 32 to 36.

From week 32 to week 36, the model presented, in average, a 2.4% deviation from the real production.

The prediction depends on the recipe group, the operation of the production line and also the order of production. The order is important because there are typical starting recipes that have higher fixed losses than the other recipes. If these recipes do not occur in the beginning of the week or if one recipe that is not usual to be a starter comes first, the model will not be able to predict these untypical situations.

The model can also predict productions for recipes that were not previously produced. To do so, the user must fit it in an existing recipe group according to the division illustrated in Figure 6. The model was also tested to new recipes, and it presented similar results to the more usual recipes.

To help the user understand if a given prediction is accurate or reliable, there are two columns in the user interface, one with the number of historical records concerning the recipe group, the other with the average level of trust calculated with the tested data, which gives the value of the accuracy of the prediction of a certain recipe group.

Table 3 - Model's user interface.

Raw Materials	%H Raw Materials	%H Final Product	Set of Drum Dryers		Final Product	Losses	Average Output	Level of Trust	Number of entries in the collected data
kg			1+2	3+4					
1 000					kg	%	kg/h	%	
Plain Cereals		Without Hidrolysis	Film	Corn and Rice	725	27,5%	540	96,3%	17
				Rice	704	29,6%	545	98,1%	14
				Wheat Semolina	767	23,3%	464	96,8%	9
			Final Product	Rice	778	22,2%	575	95,0%	13
		With Hidrolysis	Film	Wheat Semolina	754	24,6%	529		1
				Rice	748	25,2%	595	93,4%	2
			Final Product	Multicereals	743	25,7%	473	98,2%	29
				Rice and Sugar	692	30,8%	531	98,0%	3
				Rice and Tapioca	741	25,9%	679		1
		With Husk	Without Hidrolysis		709	29,1%	488	89,9%	9
			With Hidrolysis		760	24,0%	415	96,8%	3
Milk Cereals		Without Hidrolysis	Film	Wheat	742	25,8%	595	95,5%	8
			Final Product	Rice	762	23,8%	548	98,4%	19
				Wheat	756	24,4%	575	97,9%	28
		With Hidrolysis	Final Product	Rice	712	28,8%	544		4
				Wheat	768	23,2%	507	99,0%	9

The model was compared with the previous method to predict losses in the process. This method consists in applying a percentage of the total raw materials, according to each individual recipe.

Comparing both methods during the validation weeks, the model presented a 2.4% deviation whilst the old method had a 3.1% deviation. So the model gives a better prediction of the process losses and can be applied to new recipes.

5. Different Approaches

Cutter's influence

Both sets of drum dryers have the same principle of operation but there is a difference between them. The drum dryers 1+2 have cutters prior to the transporters. The purpose is to break the product sheet so it doesn't wrap around the transporters. This set of drum dryers are mainly used for recipes with sugar content because the sheet of this recipes tend to have a plastic behaviour and the transporters by themselves tend not to break the sheet properly. So it is expected to have more process losses in the gravimetric separator of the set of the drum dryers 3+4. Figure 11 illustrates the relation between the gravimetric separator losses at both sets of drum dryers.

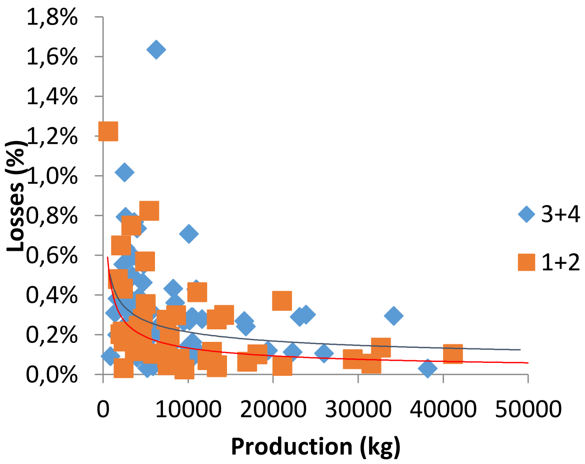

Figure 11 - Losses in the gravimetric seperator by set of drum dryer.

The opposite relation is expected in the air filter losses from the cyclone separator, which is shown on Figure 12.

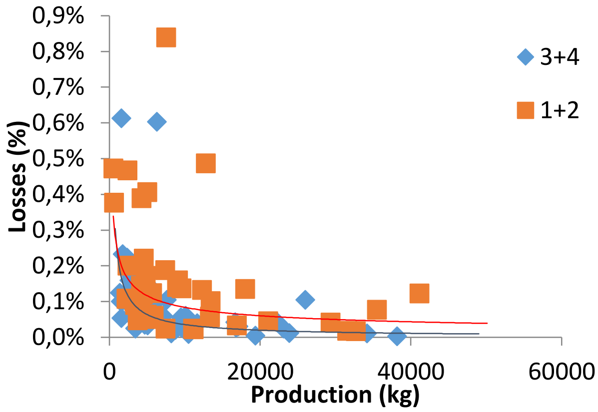

Figure 12 - Losses in the air filter by set of drum dryer.

This difference between both sets of drum dryers, in both cases, is mainly due to recipes with sugar content. For other types of recipes, the change in the set of drum dryers does not have any impact in the loss pattern.

Compressed Air

To help reduce the impact of this type of losses, a perforated tube was installed so that the compressed air that passes can help coolling the product sheet. If the temperature of the product is lowered, the sheet should have a more rigid behaviour instead of an elastic one. Being more rigid, it is easier to break so it does not wrap around the transporter.

After the installation, a verification test was made to assess if the changes caused the desired effect in the process. The data was divided in before and after the air installation, and to see if it affected the desired group of recipes, it was also divided in recipes with and without sugar. The mean losses are shown in Table 4.

Table 4 - Losses before and after the compressed air installation.

	With sugar	Without Sugar
	Gravimetric separator	
Before	0,3%	0,2%
After	0,3%	0,2%
Δ	0,0%	0,0%

From these results it was concluded that the perforated tube did not have the desired effect on the gravimetric separator.

Minitab vs. Model

The developed model was also compared with the correlations between the raw materials and final product, established by the Minitab software. This method has the advantage of needing less information than the model here developed, but it can not differenciate the types of process losses, despite having the same type of equation.

The two recipe groups with more entries in the historical data (Table 1), multicereals and wheat, originate the following equations.

$$\text{Losses (kg)} = 299{,}7 + 0{,}0723 \times \text{RM (kg)} \quad \text{Eq. 3.}$$

$$\text{Losses (kg)} = 340{,}8 + 0{,}1006 \times \text{RM (kg)} \quad \text{Eq. 4.}$$

To compare the predictions from these equations with the model and the real production, the loss percentage was calculated for all scenarios. Both groups were represented in Figure 13 and Figure 14.

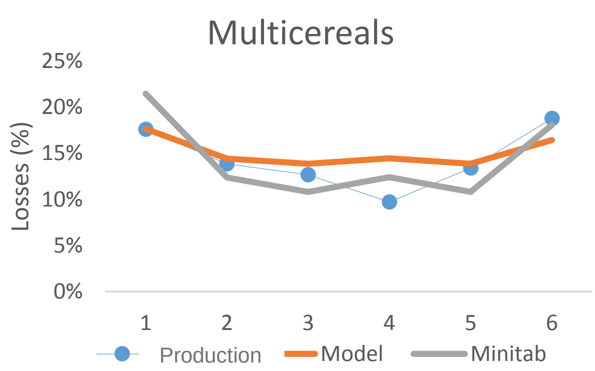

Figure 13 - Comparison between production, model and minitab (multicereals).

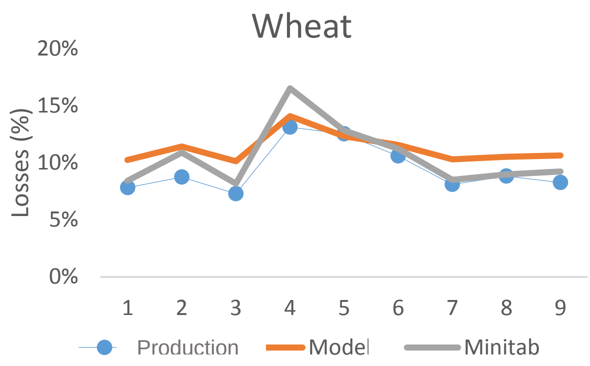

Figure 14 - Comparison between production, model and minitab (wheat).

From both figures it can be assessed that neither method has an advantage over the other. In the multicereals recipes, the model has an 1.8% average deviation, against the 2.2% from minitab. In the wheat, minitab has a better prediction, having 1.1% deviation while the model has a 2% deviation, in average.

Comparison between income groups

Taking into account the various groups of recipes created for the development of the model, it's relevant to understand which ones have higher losses.

According to the data from Table 2, the mean, maximum and minimun values were illustrated for the fixed losses (Figure 15) and variable losses (Figure 16).

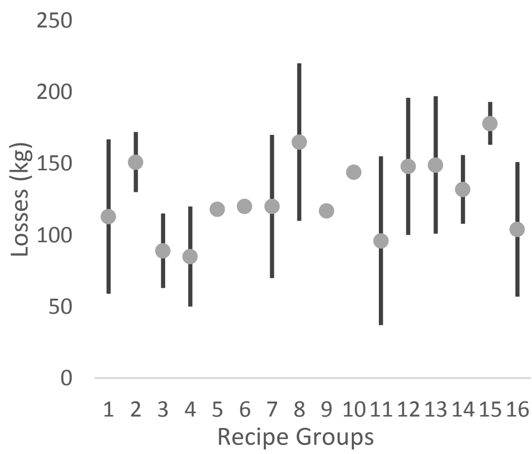

Figure 15 - Mean, maximum and minimum values for the fixed losses.

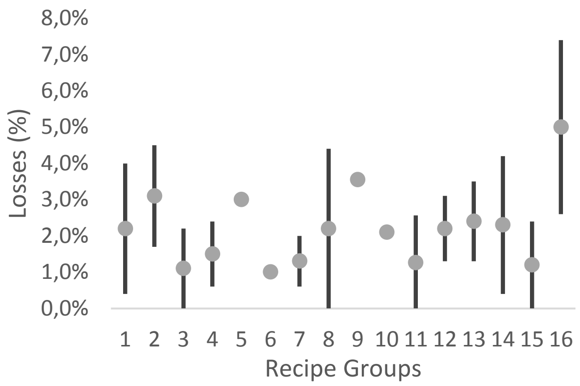

Figure 16 - Mean, maximum and minimum values for the variable losses.

where the recipe groups are numbered according to the order on the Table 3.

According to this analysis, milk cereals tend to have higher fixed losses than the rest of the groups, with the exception of the groups which have recipes that usually are the ones that start the week production.

The variable losses do not show a defined tendency.

It was no possible to attain a general trend between the losses and the composition of the recipe and the amount of raw materials.

6. Conclusions

The developed model can predict process losses with 2.4% average deviation. It can also accomodate different moisture contents in the raw materials and final product. It is also able to predict the final product of new recipes and give an average output for the production, which is an improvement from the previously used method which gives a prediction with a 3.1% average deviation.

Equation directly obtained from Minitab software do not have into consideration the type of process losses, and had not a significant improvement, when compared with the predictions from the model.

It was also concluded that the cutters have an influence in the sugar recipes but the installed compressed air does not have the desired effect.

Comparing the losses with the type of recipes, it can be observed that the ones with milk tend to have higher fixed losses that the others. For the variable losses it was not found a relation with the type of recipes.

7. References

[1] J. Tang, H. Feng e G.-Q. Shen, “Drum Drying,” em *Encyclopedia of Agricultural, Food, and Biological Engineering*, New York, Marcel Dekker, Inc., 2003, pp. 211-214.

[2] W. Ramli e W. Daud, “Drum Dryers,” em *Handbook of Industrial Drying*, 4ª ed., CRC Press, 2015, pp. 249-257.