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# Analysis of the physical quality of genetically modified and conventional maize grains in the drying and wetting processes[1]

## Análise da qualidade física de grãos de milho geneticamente modificado e convencional nos processos de secagem e umedecimento

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**ABSTRACT -** The aim of this work was to evaluate the physical quality of the genetically modified corn grains (*Herculex 30S31*) as a function of drying and wetting processes in relation to conventional corn (*AG 1051*). The experimental design was a completely randomized design, with a factorial scheme (7x3x2), seven drying or wetting times (0, 20, 40, 60, 80, 100, 120 minutes), three drying air temperatures (80, 100 and 120 °C) and two types of maize (conventional *AG 1051* and *Herculex 30S31* transgenic). The grains of transgenic and conventional corn were harvested with a water content of 13.5% (w.b.) and dried in convection oven with forced ventilation, then the same grains were submitted to a wetting process for the same time. The width, thickness, length, contraction and expansion of the grains were determined, the water contents and the electrical conductivity were determined before and after drying, after the wetting process, at each interval of twenty minutes. Drying and wetting processes adversely affected the quality of conventional and transgenic maize grains. However, when compared, transgenic corn kernels were more resistant to physical damage. It was concluded that the changes in water contents in the grains during the drying and storage operations intensify the physical losses, even if at the end the grains remain with water content favorable to storage.

**Key words:** Conventional corn *AG 1051. Herculex 30S31* transgenic maize. Quantitative and qualitative losses. Resistance of the grains in the post-harvest operations.

**RESUMO -** O objetivo deste trabalho foi avaliar a qualidade física dos grãos de milho geneticamente modificados (*Herculex* 30S31) em função dos processos de secagem e umedecimento em relação ao milho convencional (AG 1051). O delineamento experimental foi o inteiramente casualizado, com esquema fatorial (7x3x2), sete tempos de secagem ou umedecimento (0, 20, 40, 60, 80, 100, 120 minutos), três temperaturas do ar de secagem (80, 100 e 120 °C) e dois tipos de milho (*AG 1051* convencional e o *Herculex 30S31* transgênico). Os grãos de milho transgênico e convencional foram colhidos com um teor de água de 13,5% (w.b.) e secos em estufa de convecção com ventilação forçada, em seguida, os mesmos grãos foram submetidos a um processo de umedecimento pelo mesmo tempo. Foram medidas a largura, espessura, comprimento, contração e expansão dos grãos, determinados os teores de água e a condutividade elétrica antes e após a secagem, depois do processo de umedecimento, a cada intervalo de vinte minutos. Os processos de secagem e umedecimento afetaram negativamente a qualidade dos grãos de milho convencionais e transgênicos. No entanto, quando comparados, os grãos de milho transgênicos foram mais resistentes aos danos físicos. Concluiu-se que, as variações dos teores de água nos grãos durante as operações de secagem e armazenagem intensificam-se as perdas físicas, mesmo que ao final os grãos permaneçam com teores de água favoráveis ao armazenamento.

**Palavras-chave:** Milho convencional *AG 1051*. Milho transgênico *Herculex 30S31*. Perdas quantitativas e qualitativas. Resistência dos grãos nas operações pós-colheita.

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## INTRODUCTION

Genetic characteristics modified in plants provide new properties such as resistance to diseases and insects, tolerance to climatic storms, increase in quality and nutritional value of food crops, tolerance to herbicides, among others. The first commercially released genetically modified (GM) crops were developed to provide agronomic improvements, which aim to reduce crop losses and increase productivity. Two new lines in genetic engineering are currently being explored for the food industry: changing more complex metabolic pathways using multiple genes and focusing on characteristics that benefit consumers in an attempt to increase the supply and quality of food in the world (PITELLI, 2014).

Artificial drying, however, is the most critical stage in the production of agricultural products because, if it is conducted under inappropriate conditions, the damage will be irreversible, hampering commercialization or processing. Temperature, relative humidity, drying air velocity, drying rate of product, initial water content and product, drying system employed and residence time of the product in the drying chamber are the main parameters which may be associated with loss of grain quality during the drying process (BARBOSA NETO; MARQUES; PRADO; 2014; CORADI; MELO; ROCHA, 2014; COSTA *et al*., 2011; TIECKER JUNIOR *et al*., 2013).

After drying, the grains are stored and can undergo a super drying or rewetting process, depending on grain and air conditions (KOWALSKI; RAJEWSKA, 2009). The mechanism of rehydration of the grain obeys a three-phase pattern, in the first stage occurs to the activation of the grain, as a consequence of the beginning of water absorption, and, in general, very fast, completing in one or two hours. The water content reached at the end of this stage is between 35 and 40% depending on the type of reserve tissue, which normally occurs in the field, prior to the harvest stage. In the second phase, water absorption becomes almost constant, since very small increases are verified over time. The third phase is characterized by an increase in the amount of water absorbed over time in relation to the second phase and coincides with the process of cell division at the embryonic axis growth points, followed by the expansion of the plant structures (CORRÊA *et al*., 2010; OLIVEIRA *et al*., 2013; PEREA-FLORES *et al*., 2012).

In conditions of excess water, too rapid absorption can cause ruptures in the tissues of the grains, often manifested by the release of solutes and a drop in vigor (VERGARA *et al*., 1997; VERTUCCI; LEOPOLD, 1983). The absorption of water is not equivalent, considering the different tissues of the grain. The authors established the following increasing sequence of water absorption: tegument, reserve tissue and meristematic tissues. There are different levels of hydration, or critical water potentials, for each type of grain that probably controls imbibition, expansion and cell division (CORADI; FERNANDES; HELMICH, 2016; VERGARA *et al*., 1997).

The water content recommended for the commercialization of corn grains is 13.5% (w.b.), however, this water content is still much contested by industries, producers, cooperatives, warehouses, federal agencies and institutions because it is understood that corn grains with water contents above 12% (w.b.), when stored, rapidly lose their intrinsic quality. Producers have chosen to raise the water content of the grains, from the storage condition (12% w.b.) to the condition of 13.5% (w.b.) at the time of commercialization, to achieve a higher grain mass. However, this type of operation is contradictory to the functional and quality aspects of the post-harvest, making the established standards of grain water content for commercialization questionable. The other point is the maize cultivars that can be influenced in the resistant of the physical actions that provide water movement in the drying and storage processes can guarantee the quality of the products for longer storage time, allowing better technical results with reduction of weight and economic losses.

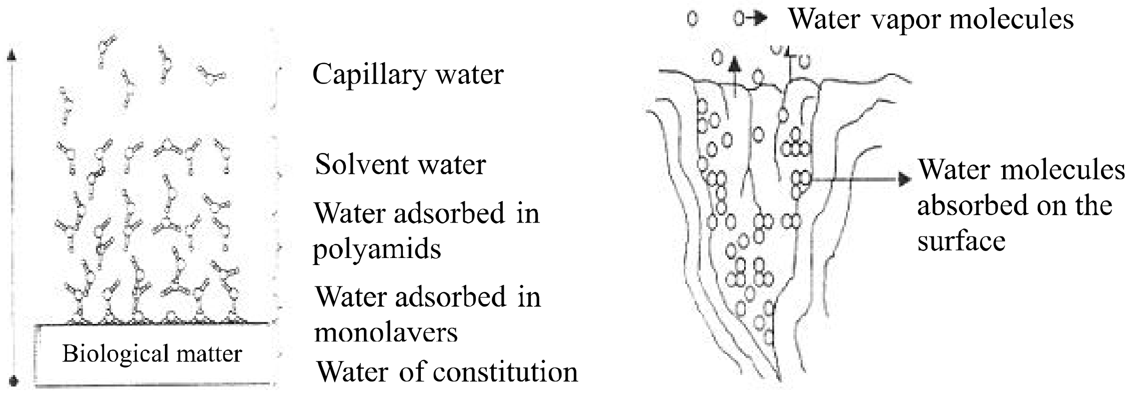
Thus, the aim of this study was to evaluate the physical quality of genetically modified corn grains (*Herculex* 30S31) in function of drying and wetting processes compared to conventional corn (*AG 1051*).

## MATERIAL AND METHODS

The experiment was conducted at the Post-Harvest Grain Laboratory of the Federal University of Mato Grosso do Sul (UFMS), Campus de Chapadão do Sul (CPCS). The experimental design was completely randomized, in a factorial scheme (7x3x2), seven drying or wetting times (0, 20, 40, 60, 80, 100, 120 minutes), three drying air temperatures (80, 100 and 120 °C) and two types of corn (conventional *AG 1051* and the transgenic *Herculex 30S31*). To evaluate the results, a variance analysis was performed and the means were compared using the Tukey test at 0.05 probability. The grains of transgenic and conventional corn were harvested with water contents of 13.5% (w.b.) and dried in a convection oven with forced air ventilation (oven TE-394/2-Tecnal). Drying was carried out until the grains reached water content of hygroscopic equilibrium with air (Figure 1).

The corn grains used for evaluation were manually selected for the formation of homogeneous and standardized lots. For each corn sample (total of 126 samples), two aluminum capsules were used, one with ten grains for measuring the width, thickness and length, and another capsule with one hundred and fifty grains for weighing (analytical balance 0.0001, model AUY-220-I) and

**Figure 1** - Water molecules inside plant cells (KONING, 1994)



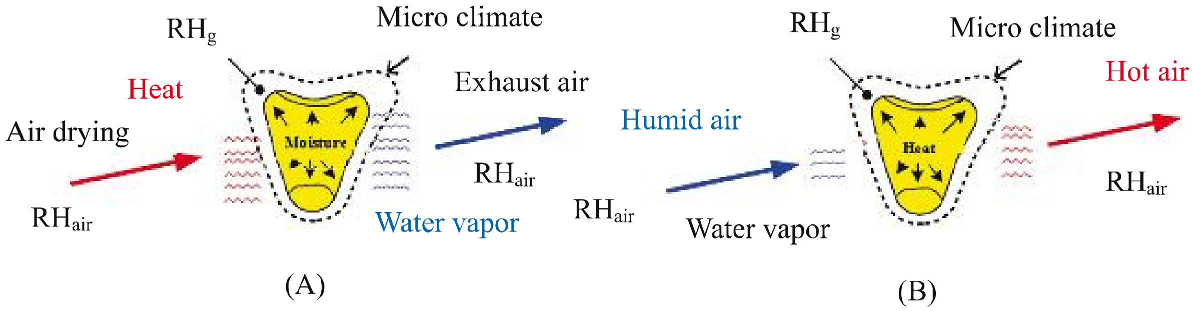

determination of the water contents, at each time interval of twenty minutes. For each weighing, a sample of seventy five grains was taken for evaluation of the electrical conductivity (CD-850 "Instrutherm" portable). Then, a sample with the same quantities of one hundred and fifty grains was submitted to the wetting process for the same drying time (Figure 2). For the wetting of the grains, a chamber (B.O.D.) (microprocessor climatic incubator model 411D 127 / 220V 350 liter) was used at a temperature of 10 °C and RH of 90% air.

The temperature and relative humidity of the environment were monitored throughout the drying and wetting using a thermohygrometer (Incoterm) of internal temperature 0 to 50 °C. After the withdrawal of each sample, they were placed in a desiccator with silica (Laborchemiker LCK-5250-VAC) for cooling and then weighed, then the ten grains measured again. The water content of the grains in (% w.b.) were determined by the gravimetric method (analytical balance 0.0001, model AUY-220-I). Grain size (length, width and thickness) was evaluated using a digital caliper (MOHSENIN, 1986). The electrical conductivity test was performed according to a methodology described by Vieira and Krzyzanowski (1999). Twenty-five grains were used for 3 sub samples of each treatment and weighed to two decimal places precision (0.01 g). The samples were placed to soak in plastic cups with 75 mL deionized water and kept in a refrigerated chamber with controlled temperature at 25 ± 2 ºC for 24 hours. The solutions containing the grains were slightly agitated for the homogenization of the leachates and immediately read in a portable CD-850 "Instrutherm" conductivity meter, the results being divided by the mass of the 25 grains and expressed in µS $cm^{-1}g^{-1}$ of grains.

## RESULTS AND DISCUSSION

Figures 3 and 4 are the results of quality as a function of drying and moistening of conventional and transgenic maize grains. As the drying time increased, the water contents of the conventional maize grains decreased, reaching the highest reduction rates in the 40 minute time. In the same way, the water adsorption process of the grains increased as the temperature and drying time increased. The water adsorption intensity of the grains increased when they were submitted to rewetting (Figures 3D, 3E, 3F and 4D, 4E and 4F). Grains, except in the case of dormancy caused by impermeability of the integument, soak or rehydrate when placed in direct

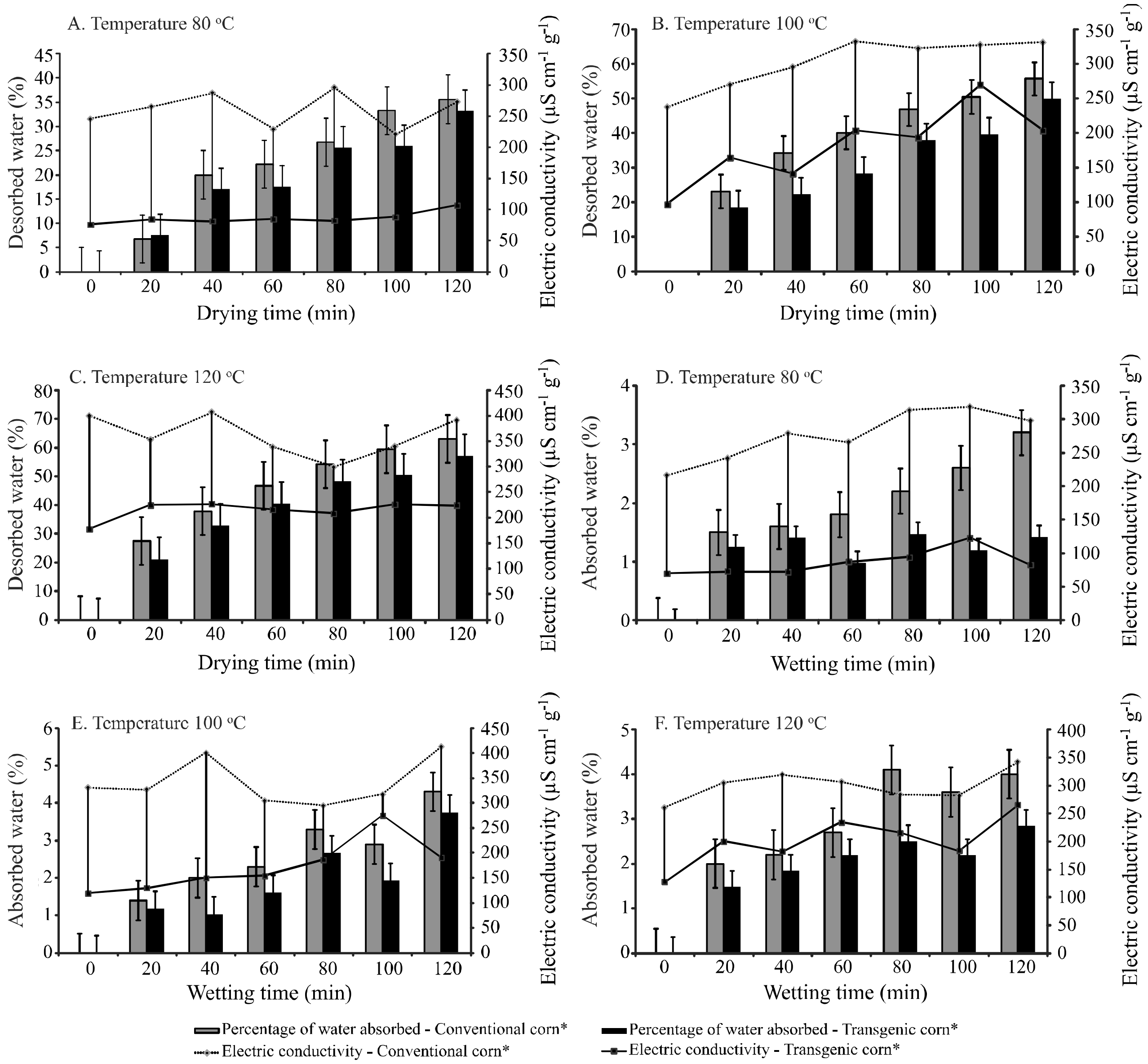
**Figure 2** - Representation of the drying process (A) and wetting (B) of corn kernels (B) (SILVA, 2008)



contact with water or when exposed to environments with high relative humidity. Thus, in the wetting process, it was verified that the percentages of water contents of the grains decreased as a function of the increase of the time and temperature in which the grains were submitted (Figures 3A, 3B, 3C and 4A, 4B, 4C).

The movement of water molecules between two systems depends on the water potential difference between them (POWELL; MATTHEWS, 1978). Thus, it was observed that the percentage of water absorbed in the wetting, for the beans submitted to drying with a temperature of 80 ºC was increasing, already for the temperatures of 100 ºC and 120 ºC there was an increase in the absorbed water contents until the time of eighty minutes, from this, the values varied, and in the time of one hundred minutes the water contents decreased and in the time of one hundred and twenty minutes they increased again for the wetting conditions. The natural tendency is for the movement to occur in the direction of the largest to the least water potential. The water potential of the grain increases, reducing the gradient with the wet substrate, thus, the hydraulic flow of the grain increases and tends to match the substrate (CORADI *et al.*, 2016; POWELL; MATTHEWS, 1978).

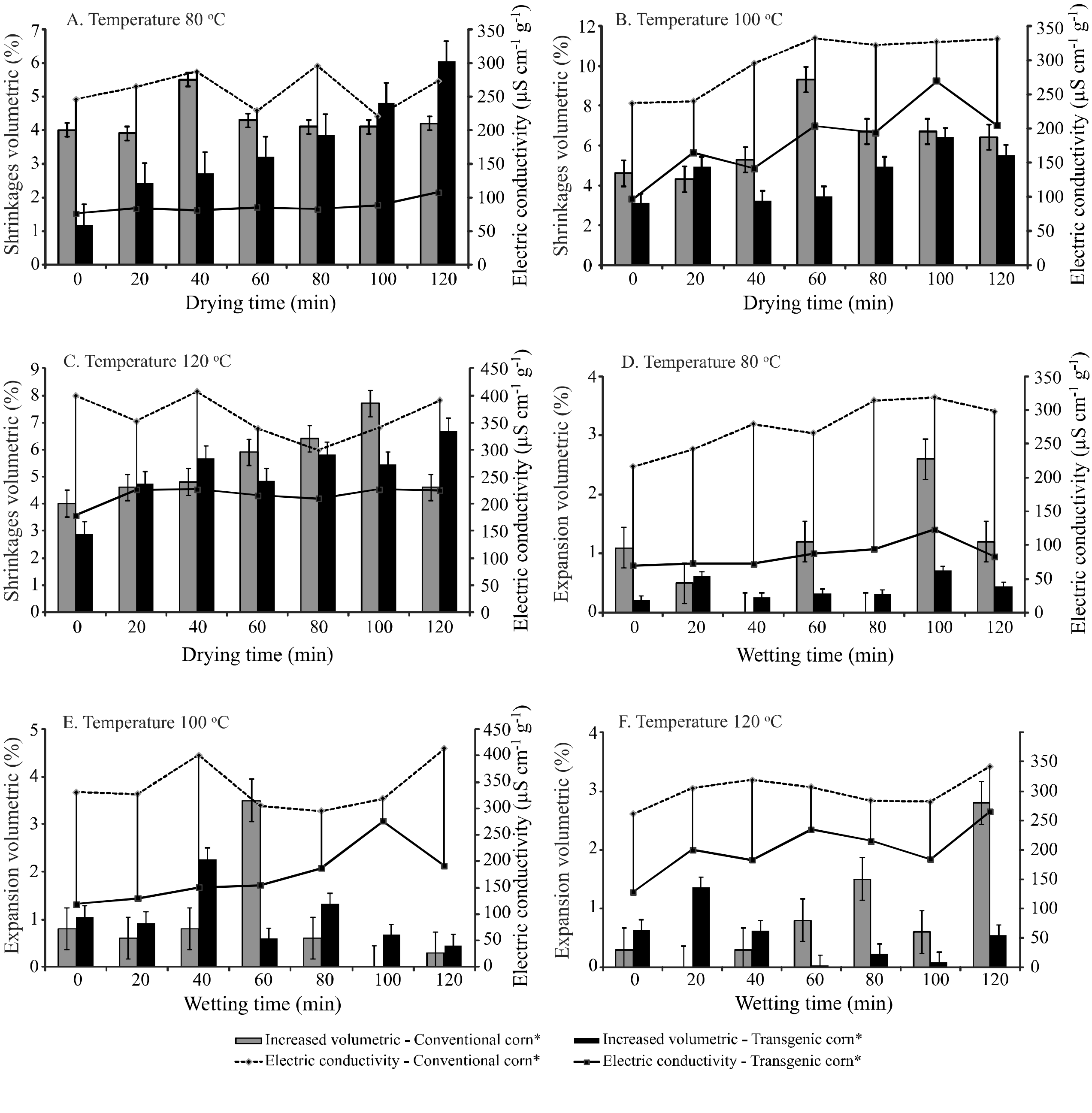
**Figure 3 -** Evaluation of the percentage of desorbed and absorbed water x electrical conductivity in conventional and transgenic *Herculex 30S31* maize grains during the drying and wetting processes



The temperature had a great influence on the drying process and the grain quality. It was evidenced that the same drying time was not enough to rehydrate the grains through the wetting process (Figures 3D, 3E, 3F and 4D, 4E, 4F). The loss of grain quality with the ion leaching was verified by the electrical conductivity, that is, the grain rewetting contributed to the reduction of quality in similar proportions of the drying. However, the highest values of electrical conductivity coincided with the higher temperature treatments. These conditions caused a higher leaching of ions in the structure of the cellular tissues that make up the formation of the grains, that is, a greater disorganization of membranes, possibly caused by oxidation of the lipids (CORADI; MELO; ROCHA, 2014).

It can be considered that the increase of the water content in the grains to the allowed conditions of commercialization (13,5% w.b.) (BRASIL, 2012) via re-watering, can be an alternative for the increase of the mass of grains, nevertheless, evident the loss of quality. It was

**Figure 4** - Evaluation of the contraction and volumetric expansion x electrical conductivity in conventional and transgenic *Herculex 30S31* maize grains during the drying and wetting processes



observed in the drying with temperature of 80 °C that in the times of twenty and forty minutes occurred reduction of the volume of the grains. In the drying with temperature of 100 ºC the greater reduction of the volume of the grains occurred in the interval of zero to twenty minutes. At the drying temperature of 120 °C a greater grain volume reduction was observed in the time interval from zero to one hundred minutes. During drying, the grains underwent several physical changes caused by variations in drying temperature and changes in grain moisture, which caused water and thermal stresses, expansion, contraction and irreversible changes in grain density and porosity. In relation to drying, attention should be given to the temperature of the grain mass and the temperature of the drying air. Although there should be great concern about the drying air temperature in high temperature systems, the temperature reached by the grains is more important for preventing damage. When it comes to seeds this concern should be even greater due to damage to the embryo that can be caused by excessive temperatures.

With the wetting of the beans after drying at a temperature of 80 °C there was a reduction in the volume in the time interval from zero to forty minutes, increasing in volume between forty and sixty minutes. After drying at 100 °C there was a reduction in volume in the time interval of zero and twenty minutes, increasing the volume of the grains in the interval of forty and sixty minutes. While in the treatment of wetting of the beans after drying with a temperature of 120 °C, the volume was reduced in the time interval from zero to twenty minutes, increasing again in the range of forty to eighty minutes.

As the drying time increased, the water contents of the transgenic maize grains decreased for all temperatures, as happened for conventional maize, but gradually between the time intervals. The same was evidenced with the percentages of water adsorbed by the grains, that is, according to the increase of the temperature and of the drying time, it was observed larger quantities of water adsorbed by the grains.

In the grain rewetting process, it was noticed that the water contents also decreased as a function of the increase of the time and temperature in which the grains were submitted. The evaluation of water absorbed when the grains were submitted to drying with a temperature of 80 ºC did not present linear increase, and the drying times in which the highest percentages of water adsorption were forty, eighty one hundred and twenty minutes. For the drying temperatures of 100 and 120 ºC also did not occur linear increase of water absorbed by the grains, however in the two temperatures the time in which there was the greater percentage of water absorbed was in one hundred and twenty minutes. Many negative water potentials, especially in the beginning of the imbibition, influence the water absorption, being able to prevent the sequence of the events related to the germination process of the seeds. The rate of water uptake by grain depends on factors such as species, water availability, contact area, temperature (CORADI; FERNANDES; HELMICH, 2016; VERGARA *et al.*, 1997; VERTUCCI; LEOPOLD, 1983), the nature of the reserve material, the permeability of the tegument, the osmotic pressure of the water, the exposure time to the humid environment, the initial water content and the physiological quality. Although also dependent on these factors, the volume of water absorbed by the grain rarely exceeds 2 to 3 times its dry mass.

The loss of grain quality with ion leaching was verified by the electrical conductivity as the temperature increased, as occurred for conventional corn, both for the drying process, as well as for the rewetting process. However, in the wetting there was no progressive increase of the electrical conductivity, but in all cases the highest values were evidenced by the higher temperatures. As recommended by the literature and the reports of some authors, the amounts of leached ions are directly related to the disruption of cell membranes and loss of grain quality. In addition to protecting the embryo, the integument regulates the absorption of water by the grain. Initially, the tegument acts as regulator of the process, but later, it favors the entrance of water, allowing uniform hydration. The permeability of the tegument to water increases with the increase of the degree of deterioration of the grains. Others authors associated the permeability of the integument to the size of the grain, indicating that smaller grains tend to have lower permeability (VERTUCCI; LEOPOLD, 1983). This relationship between size and water absorption occurs due to the lower degree of contact with the wet substrate in small grains (ANTUNES *et al.*, 2011; CORADI; FERNANDES; HELMICH, 2016; VERTUCCI; LEOPOLD, 1983). However, the authors verified a difference in the absorption rate, especially in the first three hours of contact with the wet substrate. During this period the smaller grains absorbed water faster, while the larger grains absorbed more slowly. However, the absorption rates, as well as the differences between them, decreased with the progression of the imbibition period, reducing the distinction between size classes (CORADI; FERNANDES; HELMICH, 2016; VERTUCCI; LEOPOLD, 1983).

Volumetric changes of products due to water withdrawal are reported as the main causes of changes in the main physical properties of agricultural products (HASHEMI; MOWLA; KAZEMEINI, 2009; SIQUEIRA; RESENDE; CHAVES, 2011). It was observed for drying at a temperature of 80 °C that there was volume reduction according to the drying time. For the drying temperatures of 100 and 120 °C, the values varied according to the drying time in which the grains were submitted, and the largest volume reductions occurred at one hundred and one hundred and twenty minutes, respectively. In studies to evaluate the effect of drying air temperature and initial harvest moisture on the physiological quality and mechanical damages in maize, it was observed that the susceptibility to breaking increases with drying air temperature (CORADI; FERNANDES; HELMICH, 2016; DONDEE *et al*., 2011; SHIROMA; DARI; PENZ JUNIOR, 2011; SOUSA *et al*., 2011). In the grain rewetting process, there was a great variation in grain volume reduction, and at the drying temperature of 80 ºC the highest grain volume was obtained in a hundred and twenty minutes, at 100 ºC in the time of eighty minutes and in the Temperature of 120 °C in the time of twenty minutes.

The drying rate expresses the water content of the grains as a function of the drying time and is related to the movement of the water from the interior to the surface of the grains. This movement of the water, in turn, is dependent on the genotype, maturation stage, water content, permeability of the protective layer, physical composition of the seed lot, temperature, relative humidity, air flow and of the drying method. The drying rate may also be a function of the chemical composition of the beans and the method used in the process. The drying rate depends on grain characteristics and grain and air interface properties ( CORADI; FERNANDES; HELMICH, 2016; NUTHONG *et al*., 2011; SOUSA *et al*., 2011). With increasing drying time the water content of corn kernels decreased for all temperatures, but the water content of conventional maize fell more than that of transgenic maize.

The same was evidenced with the percentages of water adsorbed by the grains, as the temperature and the drying time were increasing the amount of adsorbed water was higher, but the water adsorbed by the conventional corn was higher than that of the transgenic maize. For the wetting of the grains it was noticed that the water contents also decreased as a function of the increase of the time and the temperature in which the grains were submitted, as it was seen in the drying, the water content of the conventional corn was lower than the of transgenic maize for the same conditions. Due to the fact that conventional maize lost and gained water more easily, it ended up having greater physical damage to the grain, consequently higher values of electrical conductivity when compared to transgenic maize.

It was generally observed that conventional corn was generally found to have undergone larger volume changes with drying and moistening than transgenic maize. The imbibing corn grains occurs by two different paths. First, by the rapid entry of water through the black layer, leading to the hydration of the embryo, and second by the movement of a moist front that penetrates the pericarp and slowly advances through the endosperm. The intake of water corn grains is regulated by complex chemical (chemical composition) and physical (anatomy) factors.

There is a direct relationship between the imbibition speed of the beans and the temperature. Raising the temperature increases the energy of the water, causing it to raise its diffusion pressure. At the same time, metabolic activities are also increased, which reduces the internal potential, providing greater water absorption. In the physical process, imbibition occurs more rapidly at elevated temperatures. However, the final amount of water absorbed is virtually the same regardless of temperature. In conditions of excess water imbibition, too fast, can cause disorganization of the cell membrane or ruptures in its tissues, favoring the process of anaerobic respiration and, in addition, generate losses due to lack of oxygen due to insufficient aeration. The reflexes of the injuries caused by the accelerated imbibition are manifested by the increase of abnormalities and reduction in the vigor of the seedlings.

## CONCLUSIONS

1. Drying and wetting processes adversely affected the quality of conventional and transgenic maize grains. However, when compared, transgenic corn kernels were more resistant to physical damage;
2. It was concluded that the changes in water contents in the grains during the drying and storage operations intensify the physical losses, even if at the end the grains remain with water content favorable to storage.

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