RYE GRAIN QUALITY: INFLUENCE OF STORAGE CONDITIONS

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***Abstract*— The germination power of a local variety of rye grain (var. Don Ewald INTA) has been studied. They have been rewetted at different moisture levels, 10, 12.5, 15 and 17.5% wet basis (w.b.), and have been stored at 10, 20, 30 and 40°C. Weekly samples of each moisture and temperature condition were taken, to carry out the germination tests of the material. It has been found that the germination power of the seeds decreases with the storage time, following first order kinetics. Moisture content and temperature during storage affect kinetics, such that any increase in temperature or moisture content manifests itself as an increase in the rate of deterioration of the seed. The best conditions of preservation of germination power were achieved with samples of 10% moisture (w.b.) stored at 10°C. A mathematical expression is presented that models the spoilage.**

***Keywords*— Rye, germination, moisture, storage, spoilage**

I. INTRODUCTION

The Younger Dryas (10,800 BC), is a sudden cooling climate change event that lead to an ice age that lasted about a thousand years (Melott *et al*., 2010; Mills *et al*., 2014; Wolbach *et al*., 2018a; Wolbach *et al*., 2018b).

Wild cereals were particularly affected by this event causing a reduction in their yields. Consequently, all the cultivation practices that began in the Middle East during the early Natufian (weeding, transplanting, watering, pest control) became essential to ensure adequate nutrition (Bar-Yosef and Belfer-Cohen, 2002)

The domestication of cereals was influenced by natural and anthropic selection, giving rise to a series of biochemical, physiological and genetic changes, which altered the dispersal and fertilization mechanisms, causing a dependence between the plant and human care for its effective reproduction (Harlan, 1987; Munro, 2003). The strongest evidence for anthropic selection comes from the Abu Hureyra site in Syria, excavated in the 1970s. Rounded rye (*Secale cereale L.*) seeds were found there, an unequivocal sign of prolonged anthropic selection. The researchers concluded that rye (*Secale cereale L.*) and perhaps other grains were domesticated in that region at the beginning of the Younger Dryas. (Harlan, 1992; Dirzo *et al*., 2001).

One of the most notable characteristics of rye (*Secale cereale L.*) seeds and other cereals is their ability to tolerate dehydration, allowing them to be stored without significant loss of viability. The primary purpose of storing cheap plant seeds is to preserve stock for planting from one season to the next.

With the start of agriculture, man expanded his comprehension of seed requisites for maintenance of viability and methodologies to provide adequate storage conditions. In 1832, Augustin Pyramus de Candolle included a chapter on the preservation of seeds in his work "Physiologie Végétale". In it he pointed out that the vitality of the seeds would be prolonged if they were stored in conditions that protect them from heat, moisture and oxygen (Haferkamp *et al*., 1953).

Rye seeds as well as those of most crop species are considered mature when they reach maximum dry weight, and are at their highest vigor. From this moment, the vigor gradually diminishes and finally dies out.

Not all life processes take place at the same speed in different seeds of a given batch. Woodstock (1973) has expressed: "When seeds are stored, these vital processes can be stopped in individual seeds at different times. Seed death is a gradual and cumulative process as more and more cells die, until certain critical parts of the seed become unable to perform their essential function". Germination is the primary and most sensitive factor in assessing the level of spoilage of any stored seed (Justice and Bass, 1978).

Information available in the literature is found in the form of tables, nomographies and graphs, which allow evaluating the safe storage period of different seeds of agronomic interest (Ellis, 1991; Karunakaran *et al*., 2001; Sathya *et al*., 2008). The available germination data for rye (*Secale cereale L.*) was obtained from tests carried out on samples of a small number of seeds and presented in the form of a graph (Sathya *et al*., 2008; Rajarammanna *et al*., 2010).

In the present work, the influence of abiotic variables on progress of the deterioration of rye seeds during their storage in different environments (temperature and moisture content) were studied using the germination power as a method for their evaluation. The resulting information is applied to the development of a mathematical model for the prediction of spoilage.

II. MATERIALS AND METHODS

A. Material

A local variety of diploid rye (*Secale cereale L.*) has been used, registered under the name Don Ewald INTA in the National Register of Cultivar Property (RNPC) and the National Register of Cultivars (RNC) in 2010. The material has been received with a moisture content of 9.90 ± 0.4% on a wet basis (w.b.), a weight of 1000 seeds, of 21.2 g and an initial germination rate of 92% (Moreyra *et al*., 2014; Gómez Castro *et al*., 2019).

The batch of seeds received is suitable for testing as it complies with Resolution No. 2270/93 of the secretariat of Agriculture, Livestock and Fisheries (Argentine Republic), which determines 75% as the minimum value for the germinative power of rye. (*Secale cereale L.*).

B. Material Conditioning

Four batches of 1.5 kg have been prepared, each one being rewetted to levels of 10, 12.5, 15 and 17.5% on a wet basis (w.b.) respectively. For this, water was sprayed on the material, controlling the amount added gravimetrically. The added water was calculated through a mass balance for each condition. The rewetted material was placed in covered containers that were cooled in a refrigerator at 3-5°C, mixing them every 8 h for 2 days to ensure uniform moisture content.

Each of these batches then has been divided into 10 g samples that have been packed in sealed plastic bags.

Twenty heat-sealed bags of each moisture content were taken and stored at 10 °C. This methodology was repeated at 20, 30 and 40°C. Table 1 shows the relative humidity (R.H.) existing during storage for each tested condition. Every week a sample was taken from each humidity and temperature condition, to carry out the germination test of the material.

C. Moisture content

Moisture content was determined according to Association of Official Agricultural Chemists (AOAC) methodology no. 934.06 (AOAC, 1990), using a vacuum oven. About 5 g of samples were placed in aluminum dishes in a vacuum oven and kept at 70°C for 72 h. The dried samples were then removed from the oven, cooled in a desiccator and weighed using an electronic balance with a sensitivity of 0.0001 g. The initial and final weights were used to calculate the moisture content.

D. Germination Power

Plastic boxes were used for these tests. The seeds were placed on 4 layers of filter paper soaked in water, in a 12x17 grid drawn, one seed per square (2 x 2 cm).. The boxes have been kept at 15-17°C, and were inspected on the fourth and seventh days. It was considered that rye (*Secale cereale L.*) seeds to have germinated when the radicle length reached at least 5 mm. (Rao *et al.*, 2006; ISTA, 2015).

E. Kinetic model

The kinetics of loss of germination power can be modeled by the following expression:

$$\frac{dN}{dt} = -kN^n \tag{1}$$

where N is the number of germinated seeds, t is the storage time, k is the kinetic constant, and n is the order of the process.

In this work, it was found that the first order model ($n = 1$) is the most appropriate to describe the changes in germination power.

The integration of the Eq. (1) for n = 1, gives:

$$N = N_0 \exp(-kt) \tag{2}$$

where N_0 is the initial quantity of germinated seeds ($t = 0$).

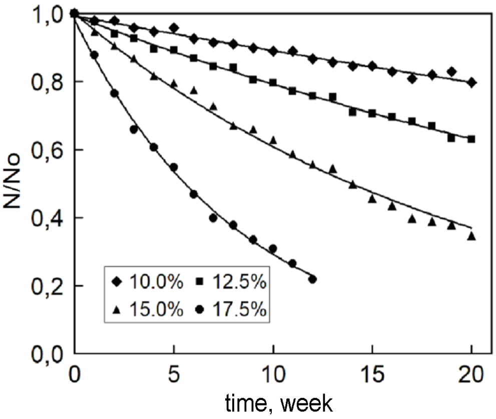

Figure 1: Reduction of the germination power at 10°C for different moisture content of the rye seed.

Towards the end of the 19th century, Arrhenius (1889), based on the work of Van't Hoff (1884), proposed that the kinetic constant could be described by the following differential equation:

$$\frac{d\ln k}{dT} = \frac{E_a}{RT^2} \tag{3}$$

where T is the absolute temperature, R is the universal gas constant, and E_a is the activation energy. After its integration, equation (3) results in the following exponential form:

$$k = k_0 \exp\left(-\frac{E_a}{RT}\right) \tag{4}$$

where k_0 is a constant called the frequency factor (Glasstone *et al.*, 1941). Equation (4) is known as the Arrhenius equation. This expression has been remarkably successful in describing the dependence of kinetics, in different degradation processes, with temperature (Demiray, 2019).

III. RESULTS

Figure 1 shows the reduction in germination power with storage time at 10 °C. This reduction in germination power increases as the moisture of the seed increases.

It is observed that the germination power decreases with increasing storage time, gradually approaching the time axis. This behavior is reproduced at 20, 30 and 40°C.

If the ordinate axis is represented on a logarithmic scale, it can be seen that now the reduction in germination power is linear for the different temperatures studied, as can be seen in Fig. 2.

The linear behavior observed in this form of representation indicates that the reduction in the germination capacity of the seeds follows first-order kinetics (Eq. (2)). The behavior is similar for 10, 15 and 17.5% moisture on a wet basis.

It can be seen that the proportion of seeds that germinate decreases with increasing grain moisture level, temperature and storage time. Similar behaviors have been previously observed in this and other cereals (Ellis, 1991; Karunakaran *et al.*, 2001; Sathya *et al.*, 2008).

Table 1 shows the values of the kinetic constant k, for different values of temperature and moisture of the grain during storage. The value of this parameter increases

Table 1: Values of the speed constant (*k*) obtained by adjusting the experimental values with Eq. (2)

moisture, *w* (w.b.)		10°C	20°C	30°C	40°C	E_a (kJ/mol)
0.100	*k*	0.0109	0.0134	0.0279	0.0357	31.60
	R^2	0.9790	0.9875	0.9897	0.9947	
	R.H.%	36	56	73	83	
0.125	*k*	0.0227	0.0398	0.0584	0.0955	34.62
	R^2	0.9946	0.9919	0.9909	0.9847	
	R.H.%	41	60	75	84	
0.150	*k*	0,0471	0.0745	0.1172	0.4052	48.09
	R^2	0.9925	0.9937	0.9963	0.9969	
	R.H.%	46	65	78	87	
0.175	*k*	0.1233	0.1439	0.2751	1.3799	57.43
	R^2	0.9914	0.9959	0.9948	0.9988	
	R.H.%	51	69	80	88	

R^2: coefficient of determination

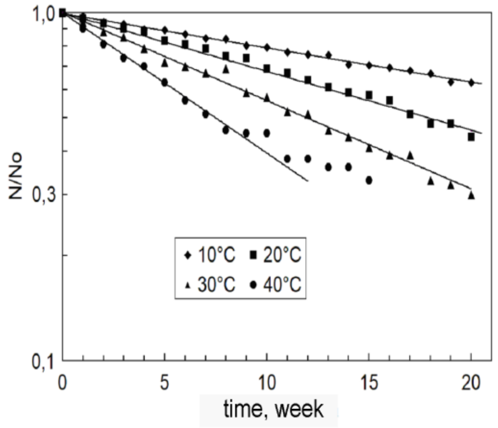

Figure 2: Germination power: Influence of storage temperature on rye seeds with 12.5% (w.b.) moisture content

with increasing storage temperature and moisture content.

Table 1 shows the values of the kinetic constant k, for different values of temperature and moisture of the grain during storage. The value of this parameter increases with increasing storage temperature and moisture content.

To evaluate the activation energy (E_a) of the germination capacity losses process, the Arrhenius Equation, Eq. (4), which describes the dependence of the kinetic constant with absolute temperature, was used.

The energies of activation of the deterioration process, for different moisture content of the grain are presented in Table 1.

To model the non-isothermal data set, and its dependence on the moisture content of the rye seed, the following Equation is proposed:

$$\frac{N}{N_0} = \exp\left[-k_1\, t \exp\left(k_2 w - \frac{k_3}{RT}\right)\right] \qquad (5)$$

w is the moisture content on a wet basis of the seed (kg/kg)

The fit to the experimental data allows finding that: $k_1 = 437.17$ week^{-1}, $k_2 = 31.079$ and $k_3 = 3894.1$ K (see Fig. 3).

The experimental data at 40°C and with a moisture content of 15% (w.b.) and above, the fit is not good. As reported by other researchers, fungal growth was observed in samples with a moisture content of 17.5% (w.b.) stored at 40°C (Rajarammanna *et al.*, 2010; Nithya *et al*., 2011).

This suggests that under these conditions other deterioration processes appear that act synergistically on the loss of germination power. Borreani *et al*. (2018) have reported that prolonged storage at temperatures of 40°C and higher can cause damage to proteins (denaturation).

IV. CONCLUSIONS

The storage of rye seeds is a critical stage, whether for sowing, conservation in germplasm banks or for subsequent malting.

The germination power of the seeds decreases with the storage time, following first-order kinetics.

Moisture content affects kinetics, such that any increase in moisture content manifests itself as an increase in the rate of seed spoilage.

Storage temperature plays a similar role. At higher temperature values, higher rates of loss of germination power are observed, which are manifested by increasing the parameter *k*, as predicted by the Arrhenius Equation.

The best conditions for preservation of germination power were achieved with samples of 10% moisture stored at 10 °C.

The proposed modeling Equation (Eq. 5) allows evaluating the loss of germination power with storage time, for any condition in the range of moisture content and temperatures studied, and based, on this information, define the sowing density to be used, or its usefulness as a raw material for the malting process.

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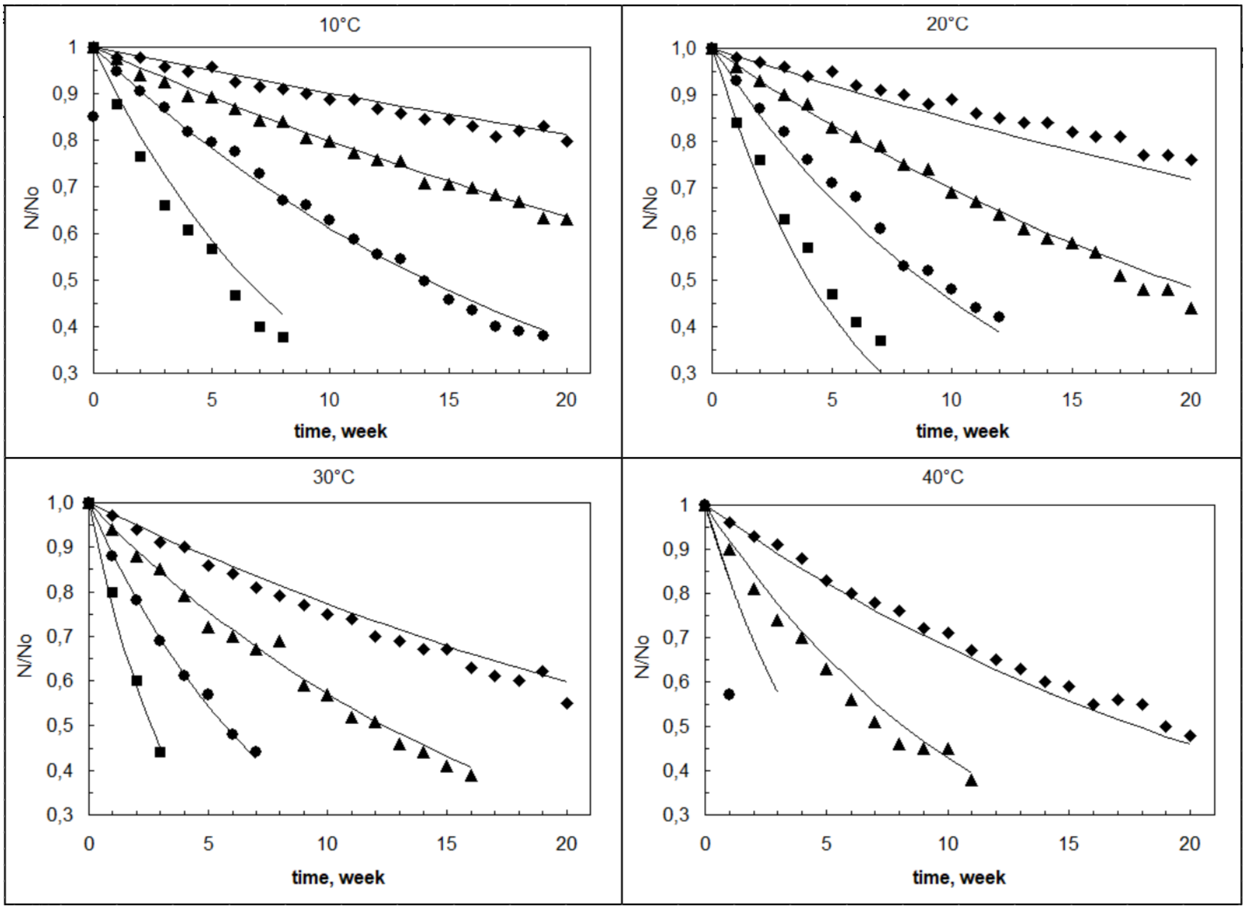

Figure 3: Fitting of experimental values using Eq. (5) (Moisture content (w.b.): ◆: 0.100; ▲: 0.125; ●: 0.150; ■: 0.175)

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