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RESEARCH ARTICLE

GENOTYPE x ENVIRONMENT INTERACTION UNDER INDUSTRIAL AND PHYSIOLOGICAL QUALITY OF WHEAT SEEDS

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ABSTRACT

Agriculture is an activity largely dependent on climatic factors, where changes may affect productivity and crop management, as well as social, economic and political factors. As the main crop producer of winter grains in southern Brazil, wheat may suffer from possible negative impacts of climate variations, being necessary to adjust the production system. The duration of wheat development stages depends on their sensitivity to photoperiod, vernalization and length of its basal phase. Temperature, water, solar radiation, nutrition, pests, diseases and weeds occurrence are variables that influence plants growth and development, therefore, the final product of economic interest, the grains. Thus, the prevailing trend is to combine different tests results, always considering the final purpose, however not always the most suitable test for assessing the seedlings emergence potential is the most suitable for detecting differences between the seed lots storage potential.

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INTRODUCTION

Since ancient times, the wheat served to sustain civilizations originated in the Mesopotamia and Nile region, and sometime later, it conquered Europe (Carvalho & Nakagawa, 1988). Over the years, the technology of production of this cereal has spread around the world (Brum & Heck, 2005) ranking third in volume of production worldwide. Due to its adaptation to many types of soil and climate, wheat growing range extends from 30 to 60° of the North latitude and 20 to 40° of the south latitude, in particular conditions, it is also grown on the equator and Arctic Circle (Quaglia, 1991). In Brazil, the wheat story began in 1534 when the ships of MartimAfonso de Sousa brought the first seeds of the cereal to be released in the São Vicente Captaincy lands, now São Paulo, from where they were spread to all others, reaching the Marajó Island, whose plantations eventually became famous (Brum *et al*., 2004). In the mid-nineteenth century, the wheat fields were attacked by rust, nearly disappearing until the First World War. From this period, the Brazilian government began to be more interested in the issue, granting awards to producers and encouraging experimental researches. With this incentive, wheat crop was resumed, and new cultivars of higher rust resistance where developed (FIPR, 2006).

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Wheat economic aspects in Brazil

By the early twentieth century, the vast majority of the population lived in rural areas, wheat consumption was still small, not requiring massive imports. With the industrialization and urbanization process, since the First World War (1914/1918), wheat consumption started to grow significantly, and with it, the need for more cereal imports (Brum &Heck,

2005). Wheat production was important until the early 1820s, when it fell into decline. The main cause of wheat decline was the rust attack, a disease which reached the fields and significantly decreased productivity (Zarth, 2002). The first official measures aiming a technically advanced wheat production in Rio Grande do Sul were taken in 1928 by Getúlio Vargas, State president. Experimental phytosanitary stations were created, when Brazilian researches gave rise to new varieties better adapted to regional climate. After 1930, with Getulio Vargas in the Presidency of the Republic, concerns were raised in relation to wheat domestic production, which resulted in several legal measures in a crescent state intervention on the sector (Brum & Heck, 2005). With the beginning of State purchases, in 1967, wheat started a growing phase in cultivated area, however with the end of State purchases, in 1990, the cultivated area began to decline. Wheat crop is going through an uncertainty phase, caused by several factors, such as: the end of the purchase by the state, competition with imported wheat from the Common Market of the Southern Cone (Mercosur), internal production costs and the uncertainties of a free market system. More than 50% of the wheat in Brazil is imported, and production is concentrated almost exclusively in the southern region. The annual consumption in the country has remained around 11 million tons (Gutkoski *et al*, 2011), with a consumption per capita smaller than 60 kg of wheat/citizen/year. Globally, wheat ranks third in volume of production. In Brazil, the annual production ranges between 5 and 6 million tons, being grown in the South (RS, SC and PR), Southeast (MG and SP) and Center- west (MS, GO and DF). The projected wheat production for 2021/2022 is 6.9 million tons, and consumption of 11.7 million tons. Wheat domestic consumption in the country is expected to grow on average of 1.2% per year between 2011/12 and 2021/2022, domestic supply will require imports of 6.2 million tons in 2021/2022 (Gasques*et al*., 2012).

Environmental effect on wheat production

Agriculture is an activity largely dependent on climatic factors, where changes may affect productivity and crop management, as well as social, economic and political factors. The farm conditions might be variable, placing them into vulnerable positions, according to different climate scenarios (Nobre, 2004).As the main crop producer of winter grains in southern Brazil, wheat may suffer from possible negative impacts of climate variations, being necessary to adjust the production system (Luiz *et al*., 2005). Among the climatic effects that most affect agricultural productivity in the world, temperature and precipitation stand out. Temperature is limiting for crops in a way that the geographical distribution of plant species on the globe is confined to thermal limits tolerated by each species or cultivar. On the other hand, the hydric availability is the factor that causes most frustrations in crop production worldwide (Caramori, 2003). The duration of wheat development stages depends on their sensitivity to photoperiod (day length) vernalization (exposure to low temperature) and length of its basal phase (intrinsic earlines). Thus, wheat cultivars sensitivity to photoperiod, vernalization and baseline length may widely vary in each stage of development (Rodrigues *et al*., 2013). The time of wheat development stages occurrence is determined by weather conditions, which are inherent of the site and sowing time (Alberto, 2008). Temperature, water, solar radiation, nutrition, pests, diseases and weeds occurrence are variables that influence plants growth and development, therefore, the final product of economic interest, the grains. If one of these variables is below a suitable level, it will be limiting grain yield, regardless the adequate levels of all other (Cunha & Pirez, 2005). Rainfall excess in wheat late maturation period causes a reduction of specific weight, also called testing weight, and when smaller than 78, the remuneration is lower, causing losses to the producer. This index also reflects in the grain flour yield (Abrecht, 2009). The occurrence of rain before and during harvest may induce seed germination still on the ear, identified as one of the main reasons of quality reduction of the wheat produced in Brazil (Bassoi, 2004). According to Gavazza (2010), when germination in the ear occurs, there are serious consequences for the processing industries. The environmental influence on seeds development is mainly translated by variations in size, weight, physiological potential and sanity (Marcos Filho, 2015). It is observed a reduction of protein and nitrogen content in agricultural years of high rainfall (wheat, barley, oats) or under poorly controlled irrigation. In this situation, there may be elevated levels of phosphorus, calcium and magnesium, less soluble components. High temperatures during maturation also causes reduction of photosynthate translocation to the seeds, especially during periods of low rainfall rates. Under these conditions, the maturation is "forced", being produced low vigor seeds (FrançaNeto *et al*., 1993), because the natural deposition of carbohydrates, lipids and proteins does not occur. On the other hand, drought stress during flowering or at the beginning of seed formation results in reduced number of seeds, with no significant effect on physiologic potential (Dornbos Jr., 1995). For seed multiplication, preference should be given to fertile soils, where higher yields and better quality of seeds are verified. NPK nutrients (nitrogen, phosphorus and potassium) are needed for new organs formation and development, and reserve material accumulation. Therefore, the nutrients availability influences the formation of the embryo, reserve organ, and protector tissue, as well as their chemical composition, and consequently, their physiological and physical quality (Peske*et al*., 2012).

Wheat seed structure

Two distinct parts are identified in the seeds: the pericarp and the seed. The pericarp covers the seed and firmly adheres to the seed layer. The germ or embryo isadhered to the endosperm and the set is covered by a thin aleurone layer (Miranda, 2006). According to Posner (2000), wheat seeds present variable sizes and colors, oval shape with rounded ends. At one end, there is the germ, and the fine hairs at the other. Along the ventral side, it is noted a reentrance known as "crease". The presence of this groove is a factor that difficults and particularizes wheat milling process, where a simple abrasion process to remove the bark becomes infeasible (Mousia *et al*., 2004). The outermost part of the seed is the pericarp, which is derived from ovaries of flowers and consists of six layers (epidermis, hypodermis, cell wall remains or thin cells, intermediate cells, crossed cells and tube cells) (Mousia *et al*., 2004). The endosperm is the main part of the seed, consisting of starch and storage proteins, and surrounded by the aleurone layer. The germ is the structure that contains the genetic material for developing a new plant, being separated from the endosperm by the scutellum (Belitz e Grosch, 1997). As stated by Zardo (2010), there are many wheat varieties that differ from each other especially by seed tenacity, flour extraction potential, protein content, gluten features, capacity of water absorption, and enzymatic activity. The seeds chemical composition varies depending on the environment, land and variety (Goesaert *et al*., 2005). Its constituents are not evenly distributed within the caryopsis (Miranda *et al*., 2004). Wheat flour is the major ingredient of foods based on cereals, and consists mainly of starch (70-75%), water (14%) and protein (10-12%). It also presents non-starch polysaccharides (2-3%) and lipids (2%), which occur in smaller amounts but are important for producingwheat flour derived products (Goesaert *et al*., 2005).

According to Germani (2008), the seed breathes and its metabolic activity depends on the humidity content, since most biochemical reactions take place only in the presence of a determined amount of water. The fungi also need water to develop. Thus, seeds with low humidity can be kept unchanged for years, while the wet wheat can deteriorate in a few days. For long term storage, it is recommended drying to 11%, for short periods, 13-14% is sufficient. Very low humidity has the disadvantage of leaving the most fragile seeds subject to breakage in handling. Gutkoski *et al*. (2011) affirm that moisture content is considered the most important factor for controlling stored seeds deterioration process. The starch granule is constituted by two polysaccharides: amylose and amylopectin. The proportion of these polysaccharides in the granule is genetically controlled, occurring, nowadays, plants developed by man with greater or lesser proportion of one of these components (Germani, 2008). The starch stored in the amyloplast is degraded during germination, providing energy to the development of roots and aerial parts of the plant. Generally, the intact granules (starch with water molecules at non-controlled temperature) absorbs about 1/3 of its weight in water, when it is damaged, this value increases approximately two to three times its weight. Due to this fact, the high level of damaged starch in wheat flour affect significantly the water absorption in farinograph, and the extensibility and dough resistance to extension in alveography (Ortolan, 2006). Lipids are considered more efficient energy source than carbohydrates during germination and may also have structural reserve function (Marcos Filho, 2015). The lipids in the seeds are in the form of triglycerides and its hydrolysis into free fatty acids and glycerol during storage, are the result of respiration, oxidation processes, action of enzymes, among other factors (Gutkoski *et al*., 2011). According to Germani (2008), flour contains the lipids of endosperm, germ and aleurone layer. The higher the amount of lipids in the flour, faster is the deterioration, hence the perishability of whole flour. Of the total wheat protein, 15% correspond to the globulins and albumins (not forming gluten), and 85% to gliadin (high extensibility and low elasticity) and glutenin (low extensibility and high elasticity), which form gluten, and the grain total protein amount is between 8 to 21% (Wally, 2007). Among all cereal grains, wheat proteins are the only ones to present ability to dough formation. This capacity is related to gluten formation, which plays a fundamental role in determining the wheat bread-making quality by checking the water absorption capacity, cohesiveness, elasticity and viscosity of the doughs (Gutkoski *et al*., 2011). The proteins interweaving obtained from the mixture with water and dough beating results in an elastic web responsible for retention of gases formed during dough fermentation process and water vapor during cooking process, which will give to the bread its final volume and characteristic texture (Wally, 2007). The storage proteins are related to quality parameters. Among them, Torres *et al*. (2009) include the falling number analyzes (FN), SDS-microsedmentation test (SDS-MS); alveography with its parameters: gluten strength (W); Tenacity (P); extensibility (L) and elasticity index (Ie).

Wheat industrial quality

Wheat classification destined to milling and other purposes is established by the Normative Instruction No. 38 of 2010, of the Ministry of Agriculture, Livestock and Food Supply (Brasil, 2010), according to their identity and quality requirements, in types 1, 2, 3 and out type, and classes improver, bread, basic, domestic and other uses. The type definition is based on the maximum tolerance for foreign materials, impurities and established defects (Table 1), and class according to gluten strength and or stability, and falling number (Table 2).

The genotype yield potential expression in a region depends on genetic and environmental factors, especially the photoperiod, temperature and solar radiation. Weather events, such as frost, hail, rainfall excess or deficiency, also has important effects on yield potential and wheat quality.In order to locate the cultivars in the different producing regions, set the best sowing time and optimize the evaluation of Value for Cultivation and Use (VCU) assays, it was performed a cooperation work betweenresearchers of plant breeding companies. The research aimed to divide the wheat growing regions within each state, considering primarily the water regime during crop development in the different production areas. The production chain agents should not be forgotten, being the main link to Brazilian wheat progress. Several actions are being made and still need to be carried out by research, producer, technical managers, receiving units and industry. The breeding companies have focused their efforts on developing more stable cultivars, of high gluten strength, more resistant to germination in the ear and head blight, with quality standards that meet industry demand. In Rio Grande do Sul are produced wheats on equal footing to what is best in the international market. By 2008, only 30% of the wheat produced in Rio Grande do Sul was the bread type, the most demanded by the market. Today, this trend has been reversed: 70% of the crop meets the bread-making industry. Brazilian wheat producers still have in mind that wheat is a high-risk crop, and may suffer from adverse weather, especially frosting during elongation and silking stage, and rain during pre-harvest. In order to avoid investing so much because of this "risk", the producer often fails to achieve the most correct management, saving in seeds of lower physiological quality, fungicide applications and nitrogen fertilization at inadequate time and amounts. Nevertheless, in recent years, the production system has selected producers that invest and believe in the crop.

Table 1. Classification standards for wheat types directly destined to milling and other purposes

Types	Test weight (Kg/hl)	Fallingnumber (seconds)	Foreign matter and impurities (% maximun)	Damagedby insects	Damaged by heat, moldy and rancid	Empty, wheat middling, and broken	Total defects (%)
1	78	250	1	0,5	0,5	1,5	2,5
2	75	220	1,5	1	1	2,5	4
3	72	150	2	1,5	2	5	7
Out type	< 72	< 150	> 2,00	> 1,50	10	> 5,00	> 7,00

Source: Adapted from Brazil (2010).

Table 2. Characteristics of the different classes of wheat directly destined to milling and other purposes

Classes	Glutenstrength (10^{-4} J)		Stability (min.)	Fallingnumber (sec.)
Improver	300	And	14	250
Bread	220	Or	10	220
Domestic	160	Or	6	220
Basic	100	Or	3	200
other Uses	Any		Any	Any

Source: Adapted from Brazil (2010).

The acquisition of cultivars that meet specific market niches, interaction with research organizations, seeking for identifying genotype requirements and management to be performed during crop development has shown that, in recent years, both production and grain quality are improving, proved by yields up to 5000 kg ha in technified farms and favorable climate conditions during crop development. The receiving units play a very important role in the production chain. In addition of performing the proper drying and controlling stored grain pests, the lots segregation for industry allocation becomes the best solution for Brazilian wheat valorization. The biggest obstacle in the segregation process is the decision of the lots selection method, which may interfere in the hopper unload time, investment in warehousing and logistic structure. With the accession to segregation process, the entire production chain benefits. The farmer will have the valorization of the wheat produced, encouraging them to invest more in the crop. The industry has the option of choosing lots that suit their needs, and the storage unit, intermediating producer x industry market, also earns adding value to a differentiated product. According to the Brazilian Association of Wheat Industry, of the total flour sold in Brazil, approximately 55% are intended for bread-making, 17% for pasta industry, 13% for biscuits, 11% for domestic use and 4% for other segments.

The best wheat silos will present protein percentage above 14% (Felício *et al*., 2001). The amount of protein on wheat grains may vary between 9 and 17%, depending on genetic and environmental factors, and those associated with the cultivation. A suitable wheat for bread-making should always present at least 12% of protein (Rosa Filho, 2010). As stated by Gutkoski&Neto (2002), the protein amount is related to the capability of dough formation. When wheat flour and water are mixed, the result is a dough consisting of a gluten protein web linked to the starch granules, which retain the carbon dioxide produced during fermentation process and causes bread to retain the formed gas, increasing the volume. According to Wally (2008), gluten has the function of forming and keepingdough structure until starch gelatinization in cooking, when the final bread structure is formed. The protein in the grains is slowly accumulated in the wheat endosperm tissues 20 days after anthesis. During this time, 40% of the proteins are composed by glutenins and gliadins, which are considered the major classes of grain storage proteins, and at 45 days the grain protein supply is complete (Tonon, 2010). At this phase, the nitrogen availability is necessary for protein synthesis in wheat grains. Nitrogen is translocated from tissues (leaves) to the ear during grain filling and transformed into protein. The nitrogen deficiency at this stage slightly affect the yield, but has a strong influence on the grain protein concentration (percentage of protein). In general, the strength of the flour has been synonymous of its quality, and the presence or absence of the strength factor directs the flour for a specific purpose. The expression "flour strength" is commonly used to designate the flour bigger or smaller capacity of going through a mechanical treatment, when mixed with water. It is also associated to the higher or lower water absorption capacity by gluten forming proteins, combined to carbon dioxide retention capacity (Gutkoski & Neto, 2002). According to Germani (2007), there must be a proportionality of tenacity values (P) and extensibility (L) (relation P and L) for, associated to W values (general gluten strength), expressing a suitable bread-making potential. A flour that presents P/E values below 0.60 may be considered of extensible gluten, from 0.61 to 1.20 of balanced gluten, and above 1.21 of tenacious gluten. The elasticity index (Ie) ranges from 25 to 75%, being the optimal Ie from 45 to 50%, for French bread making, in flour without correction. After addition of ascorbic acid (correction), optimum strength is between 50 and 55%. The alveography registers the curve of extension, under a given air volume pressure, of the test dough tensioned until breakage (Ortolan, 2006). To perform the alveography, a mass is prepared with wheat flour and sodium chloride solution, considering the standard water absorption. Small discs of uniform circumference and thickness are made with this mass, which are placed on a hollow half metal sphere, and through the holes in this half sphere, air is insufflated under the mass blade to form a "bubble" until its rupture. During this process, pressure variations are recorded by a manometer that expresses the values in a graph (Figure 2). From this graph are calculated: gluten strength (W), tenacity (P), extensibility or elasticity (L), and the relation tenacity/extensibility (P/L) (Guarienti, 1996).

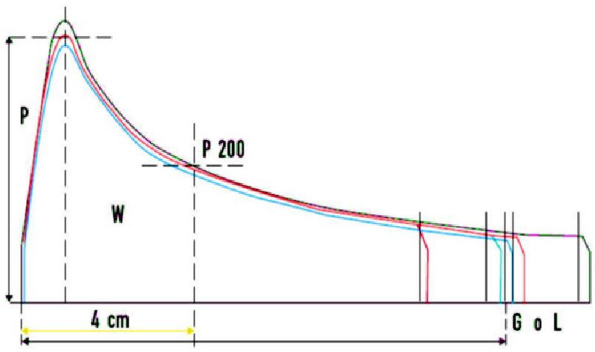

Figure 2. Example of Alveograph

Source: Institute of Food Sciences and Technology - ICTA.

In Figure 3, it can be observed graphs generated from flours of favorable rheological characteristics for producing bread, biscuits and pastas.

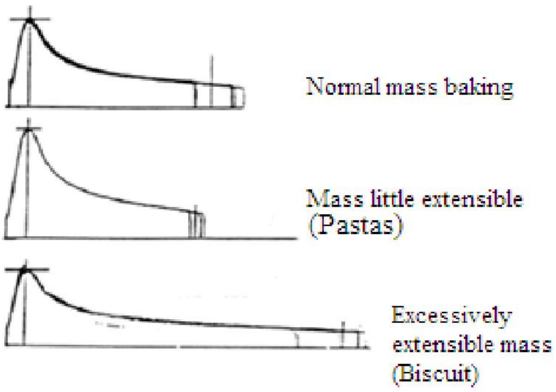

Figure 3. Typical alveogram index for pasta, breads and biscuits/cakes

Source: Institute of Food Sciences and Technology - ICTA.

The falling number test verifies the α-amylase enzyme activity on the grain in order to detect damage caused by germination in the ear. It is defined as the time, in seconds, that a piston takes to reach the base of a test tube containing a farinaceous solution of which the alpha-amylase content is being determined. Therefore, the higher the falling number, the lower the enzyme activity and starch degradation will be (Tonon, 2001). The same author, analyzing variability of the recommended wheat genotypes for Rio Grande do Sul state related to germination in the ear, verified that this characteristic expression is influenced by genotype x year x location interaction. The influence of genotype x year x location interaction may also be verified in the colors of the flour obtained from wheat grains milling. According to Ortolan (2006), the agricultural year (climatic conditions), location, genotype and pigment content also affect the color of the flour (Germani&Carvalho, 2004). Consumers give great importance to the color of the flour, preferring whiter flours, although it does not always represent the best quality. The colorimeters Hunter Lab and Minolta are the most used in colorimetry and present the results in different color bands, by color intensity (L*), ranging from 0 to 100, being zero = totally black, and 100 = totally white; chromaticity coordinates + predominant hue to red; - predominant hue to the green; + B predominant hue to yellow; - B predominant hue to blue (Minolta, 1994).

Reflexes of environmental conditions on wheat seeds physiological quality

In Brazil, there are socio-economic interest in increasing wheat production because, in addition of supplying the national grain demand, its cultivation provides straw for summer crops. However, all efforts to increase crop productivity, as breeding and utilization of more efficient cultural practices, may be frustrated if the seeds performance is a limiting factor in the production process (Lima *et al*., 2006). Seed production involves two distinct and high-tech stages: the field activity (seeding, proliferation, harvesting) and industrial activity (drying, cleaning, laboratory testing, packaging, identification or beneficiation). Production is an agricultural activity, while beneficiation is mercantile. The same producer can perform two activities or opt for the help of cooperatives, which complement the production service (Camozzato, 2010). The use of high physiological quality seeds combined with appropriate cultural practices, promote the achievement of more uniform stands and grain yield increases (Lima *et al*., 2006). As well as seed production, identifying the best environment for a breeding program efficiency is one of the biggest obstacles faced by breeders (Hagemann, 2011). According to Camozzato (2010), seed production/approved area, oscillates due to weather factors such as frost, hail or rain in harvest, which cause losses in seed fields. These losses can affect part or the entire seed field, although they are larger when occur at flowering and grains filling. The hydric deficit is considered an important stress factor for wheat crop, reducing leaf area and causing negative or positive consequences on grain yield, as the leaf area influences the plant efficient water utilization (Gondim, 2006). The seeds physiological potential evaluation is important at every breeding program stages, and also assists on decision making and adoption of appropriate management practices for quality control within the seed production system. The delayed harvest, with grains remaining in the field after physiological maturity, or drying at inadequate temperatures depending on the moisture content, contribute to undesirable changes in wheat physiological quality (Camozzato, 2010). When the environment (on the field, storage or transport) is not suitable for seeds, it will not be for cells and organelles, causing seed deterioration at different levels (Zimmer, 2012). Minor problems related to late harvest, combine cylinder speed, drying temperature, storage humidity, storage temperature, presence of fungi, rodents and insects, storage time, transport, soil temperature, accumulate damage to the seed. The seeds physiological quality is usually determined by laboratory tests that assess different aspects. For most crops, only germination and purity tests are used for classifying seed lots of high or low quality, information that are not always sufficient forcorrectlyassessing thequality of a seed lot (Boligon, 2010). Seed analysis is the technical procedures used to assess the identity and quality of a representative sample of a seed lot, being understood as quality the set of genetic, physical, physiological and sanitary attributes of the seeds (Tillmann& Menezes, 2012). Germination is a biological process that involves a large number of chemical reactions in which organic compounds, depending on favorable environmental conditions, are broken down and rearranged allowing the embryonic axis development (Zepka, 2007). Mature and dry seeds (such as wheat), in a quiescence state, are characterized by very low level of metabolic activity. In order to leave this state and start to germinate, the seed goes through an "awakening." It essentially consists of events summarized as: rehydration, withwater uptake by embryo and endosperm cells; enzymesformation and release, with the reactivation of cellular organelles and macromolecules, and reserve substances metabolism, generating metabolic energy through the cytochrome system, leading to the growth and cell division (Meredith & Pomeranz, 1985). Although germination might happen within wide temperature limits, each species has an optimum range of soil temperature to germinate (Zimmer, 2012). Some species have higher germination rates at low temperatures. According to the Rules for Seed Analysis (Brazil 2009), the ideal temperature for wheat germination is 20 ° C. The germination test aims to determine the maximum germination potential of a seed lot, which may be used to compare the quality between different lots and estimate the seed value for sowing (Tillmann & Menezes, 2012). The germination percentage verified in the laboratory represents the percentage of seeds that produced normal seedlings under conditions and time limits set by the Rules for Seed Analysis. These conditions are standardized and designed to obtain quick and complete germination of the samples. It means that the test is conducted under optimum conditions for maximum germination of the analyzed sample (Marcos Filho, 2015). Despite its widespread use, the results of the standard germination test carried out under optimum conditions in the laboratory, usually do not predict the emergence potential and seedling behavior in the field, where unfavorable conditions often occur (Amaral & Peske, 2000). A high percentage of germination in laboratory does not always result in an excellent field performance because of the diversity of environmental conditions where the seeds are subjected, which can affect in a greater or smaller proportion, the crop initial establishment (Tillmann & Menezes, 2012). The identification of the vigor as a physiological potential component, regardless of germination, had noticeable boost from 1950, during the IX Congress promoted by the International Seed Testing Association (ISTA), in Washington DC, USA. It was presented a proposal to differ the terminology and objectives of tests conducted on artificial substrates and optimal environmental conditions, evaluating the germination, from those conducted on soil or related to seedling emergence percentage, denominating them as vigor tests (Marcos Filho, 2015). One of the first references addressed to germination, deterioration, and seed vigor relation was identified by Delouche & Caldewell (1960) as representation on Figure 4. The Association of Official Seed Analysts (AOSA) says that seed vigor comprises properties that determine the potential for quick, uniform emergence, and normal seedlings development under a wide range of environmental conditions (AOSA, 1983). According to Boligon (2010), it is necessary selecting vigor tests that predict seeds performance when sown in the field, for each crop or group of crops. Evaluating the accuracy of vigor tests results is still a difficult task, because there is no test considered fully standardized, excepting for accelerated aging test in soybean and electrical conductivity test in pea (Hampton & Tekrony, 1995).

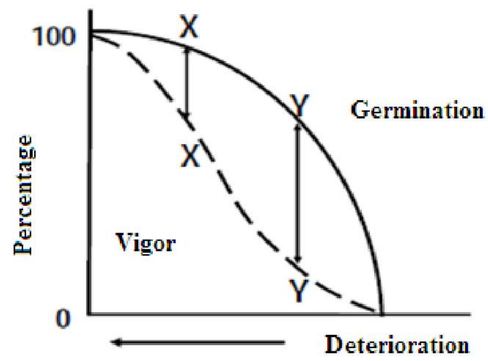

Figure 4. Hypothetical relation between germination and vigor during seeds deterioration (Delouche & Caldwell, 1960)

There are several methods of evaluating seeds vigor, some are based on cell membranes integrity (electrical conductivity and potassium leaching), stress resistance tests (accelerated aging, accelerated aging with saline solution, controlled deterioration and cold test) and tests based on seedling performance or characteristics (first counting, speed of germination, length of seedling or its parts, seedling dry matter and seedling vigor classification). The germination test first counting may be used as a vigor test, once the germination speed is reduced with seed deterioration advance. Therefore, samples showing higher germination values in the first counting may be considered more vigorous. It is a simple and easy test to perform, but usually presents low sensitivity, not detecting small differences in vigor between lots (Barros *et al*., 2009). This test is based on the principle that samples with greater percentage of normal seedlings in the first germination counting, established by the Rules for Seed Analysis (Brasil, 2009), are the most vigorous, and indirectly is evaluated the germination speed (Tillmann & Menezes, 2012). The wide variety of vigor tests and the absence of selected tests for most crops difficultits utilization when evaluating the seeds (Boligon, 2010). The efficiency of a vigor tests depends on the proper method selection, according to the intended purpose; Utilization of only one test may generate incomplete information. Thus, the prevailing trend is to combine different tests results, always considering the final purpose, however not always the most suitable test for assessing the seedlings emergence potential is the most suitable for detecting differences between the seed lots storage potential of a particular species (Marcos Filho, 2015).

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