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The importance of physiological quality of seeds for agriculture

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Abstract
Seeds present a fundamental role since the beginnings of agriculture, propelling the agricultural development of different people in different ages of human history. Its importance has been linked to the possibility of domesticating the most diverse plants in the past and, nowadays, of providing many biotechnological advancements represented by the most diverse cultivars and hybrids introduced into the market. However, the expression of all its capacities depends on the quality of this supply represented by the sum of physical, genetic, sanitary, and physiological attributes. This review shows how the physiological component of the quality of seeds has influenced the agricultural process for the most diverse crops, notedly, for major crops, forages, or vegetables. It is highlighted its central role in fulfilling the growing demands of a growing world population. We emphasize the preoccupation of research, development, and innovation actions in the sense of recognizing the factors that influence the physiological quality of seeds, developing and enhancing methods to estimate, preserve, and increase it, and how the adoption of high physiological quality seeds has influenced the development of the major crops.
Keywords: vigor; yield; major crops; forage; vegetables.

A importância da qualidade fisiológica de sementes para a agricultura

Resumo
As sementes representam papel fundamental desde os primórdios da agricultura, impulsionando o desenvolvimento agrícola dos diferentes povos, em diferentes épocas da História da humanidade. Sua importância esteve ligada à possibilidade de domesticação dos mais diversos cultivos, no passado, e, atualmente, são portadoras de inúmeros avanços biotecnológicos, representados pelas mais diversas cultivares e híbridos lançados no mercado. A expressão de todas as suas potencialidades, porém, depende da qualidade desse insumo, representada pelo somatório de atributos, físicos, genéticos, sanitários e fisiológicos. A presente revisão pretende evidenciar como o componente fisiológico da qualidade de sementes tem influenciado o progresso da agricultura para os mais diferentes cultivos, notadamente, para as espécies de grandes culturas, forrageiras e hortaliças, ressaltando seu protagonismo para o atendimento das crescentes demandas de uma população mundial em constante crescimento. Destaca-se a preocupação das ações de pesquisa, desenvolvimento e inovação no sentido de conhecer os fatores que influenciam a qualidade fisiológica das sementes, desenvolver e aprimorar métodos para estimá-la, preservá-la ou incrementá-la e como a adoção de sementes de elevada qualidade fisiológica tem impactado o desenvolvimento dos principais cultivos.
Palavras-chave: vigor; produtividade; grandes culturas; forrageiras; hortaliças.

Introduction

The domestication process of crops and the emergence of agriculture in the history of humanity confer a prominent role for the seeds. Even before the development of agricultural systems, there is archaeological evidence of seeds as food. The humanity experienced in the last two centuries, and more evidently in the last fifty years, advancements in knowledge and technology never seen before in history. It was not different in agriculture. The new technologies have contributed to the increase of yield indexes, which are constantly growing. It becomes difficult to list which discoveries had the most significant impacts in the scenario of modern agriculture compared with that used by our forefathers. However, it is unquestionable the importance of using high-quality seeds independently of the development of new technologies.

Indeed, among the essential processes, there are the discovery of the action of fertilizers and the enhancement of soil management techniques. The development of symbiotic nitrogen fixation significantly reduces the cultivation cost of species of the family Fabaceae (soybean is the main example). We are striving to reach similar efficiency in species of the family Poaceae (Grasses), whose response to the contribution of this mineral is high.

Mendel's discoveries and all the derivations from the genetic enhancement of plants permitted the development of modern cultivars that are productive and adapted to different environmental conditions. In this field, the domain of hybridization techniques has been fundamental to maximize the productive potential, as is the case of corn crops (*Zea mays* L.), by far the most important example. Similarly, genetic enhancement provided new soybean cultivars (*Glycine max* (L.) Merr.) adapted to low latitudes, propelling agriculture in Central Brazil.

In the last century, the development of chemical molecules used for weed, pest, and disease control was essential to increase crop yield. Recently, the modern techniques of Molecular Biology have permitted the development of genetically modified organisms – GMO's, which, in agriculture, are represented mainly by transgenic cultivars, whose adoption in many countries evidence its importance in world agriculture.

The examples mentioned do not minimize the importance of other discoveries. Obviously, if incorrectly used, all and every technique provides risks for the users, and, at the same time, they may be ideologically unacceptable by a part of the population. We do not aim to enter into the merits of these advancements but to present modestly and straightforwardly an evolutive analysis of the changes in agriculture.

Nowadays, to face a growing demand for food of the world population of around 8 billion people, the seeds constitute the starting point of a great deal of the almost 2 billion hectares occupied by the most varied crops that sustain the world agricultural production. In Brazil, grain production increased more than six times from 1975 to 2017, while the planted area was only duplicated in the same period. This change reflects the expressive contribution of the most diverse technological solutions provided by research institutions for agriculture. Such contributions necessarily include the use of high-quality seeds.

Seed quality is understood as the sum of attributes related to the physical and genetic purity and physiological and sanitary quality (PESKE *et al.*, 2009). **For a seed to be considered of high quality, all the attributes mentioned must be in balance and are, therefore, equally important.** The relevance of these attributes is reflected in national and international regulations about the production and selling of seeds around the world. Through normative regulations and other legal devices, minimal quality patterns are required to sell and export seed lots. In the same manner, several associations were created, during the time, to develop methods and to define patterns and criteria to subside the evaluation of seed quality, such as ISTA (*International Seed Testing Association*), acting in more than 75 countries, AOSA (*Association of Official Seed Analysts*), in the United States and Canada, and ABRATES (Associação Brasileira de Tecnologia de Sementes), in Brazil.

This review aims to demonstrate that the physiological component of seed quality has been relevant to agriculture advancements. This attribute directly impacts the phase of establishing and unforming crops with the potential to compromise the success of agricultural entrepreneurship or maximize its profit.

The physiological quality of seeds can be defined as the capacity to express vital functions, characterized by germination, vigor, viability, and longevity, parameters that interfere in the performance of the seed under field and storage conditions. The physiological quality of seeds is maximal during physiological maturity when the seed is still attached to the mother plant. For most species, there is the maximal amount of dry matter, which tends to reduce from then depending on the prevailing environmental conditions until the harvest, the harvest procedures, drying, and processing adopted, as well as the storage conditions.

The germination of seeds comprehends the succession of many ordered metabolic and biochemical phases that characterize the restart of the embryo development, generating a seedling. The success of this process is higher when there are more favorable conditions to generate it, notedly light, temperature, and water and oxygen availability, as well as the efficiency to mobilize energy reserves stored in the reserve tissues of seeds.

Responsible for the differences in the development of seeds under the most diverse environmental conditions, vigor determines the speed and uniformity of germination, emergence, and initial development of seedlings, the ability to emerge under unfavorable environmental conditions, and the germination capacity after storage periods. Vigor is genetically determined and influenced by the production environment of seeds, affected significantly by temperature, photoperiod, water and nutrients availability, and incidence of pests and diseases during the formation of seeds. Delays in the establishment of crops and unevenness in the stand are critical for reduced cycle crops or whose products are individual components of the plants, as occurs with most vegetables, from which are sold their roots, heads, bulbs in different stages of plant development. Nevertheless, in other cases, such coincidences can compromise the main crop competitivity facing weed development, affecting the productive efficiency and the maintenance of crops. This derives from the fact that there is an ideal relation between the number of plants established in a unit of area (stand) and the production expectation for all crops. Once there are failures in the obtention of an ideal stand, there is a tendency to compromise the tradable production, which is higher when the compensatory capacity of the species to minimize such fails is lower. In the case of major crops, many studies have presented the impact of using low-quality seeds in the initial establishment of the cultivation, whose effects can remain until the most advanced phases of plant development, limiting crop yield.

Seed longevity, by its turn, directly relates to the behavior during storage, which can be defined as the maximal period that a seed can stay viable under ideal storage conditions. The genotype strongly determines this characteristic. By its interaction with environmental conditions emerges the concept of viability, which corresponds to the period that a seed effectively lives within its longevity period. In this sense, besides presenting a genetically determined limit, adverse factors during the development of seeds in field conditions and after the harvest can intensify seed deterioration processes during storage and reduce their viability.

However, it is worth mentioning that the amount of water stored in the tissue of seeds (physical attribute) is directly related to its physiological quality, as it influences the intensity of the metabolic activity of the cell, which affects its capacity to stay viable during the storage period.

Considering the importance of the physiological quality to the seed performance expression, many approaches to estimate this component have been developed. Significant progress has been achieved regarding the standardizing of tests related to the seed germination analysis for most species of economic importance. Similarly, methodologies of different vigor tests have been refined by research groups dedicated to the theme. Besides, the legislation has also looked for adjusting itself to the results of such research, incorporating innovations and adjusting its norms regarding the possibilities of analysis of seeds. An example is the possibility of selling Italian rye-grass seeds (*Lolium multiflorum* L.) in Brazil, based on the results of viability obtained by tetrazolium test, permitted by the new Normative Instruction dealing with the definition of production norms, and identity and quality patterns of seeds of forage species of temperate climates.

Low physiological quality of seeds can affect the expression of gains and genetic advantages obtained by enhancement programs of different crops embedded in seeds, damaging the feedback of research actions responsible for generating and launching onto the market different cultivars and hybrids.

As aforementioned, this impact is more or less pronounced according to the cultivation referenced. Thus, to delimitate the approach of the theme, we chose to subdivide the impact of the physiological quality of seeds in major crops, forages, and vegetables.

The importance of physiological quality of seeds for the major crops

Known as one of the "raw materials" of agriculture, the seed deserves special attention in the current evolutive scenario because it cannot be considered anymore just a material of vegetative propagation, but a vehicle of technology and innovation, accessible for most farmers due to the dynamics of the production chain of seeds (BAGATELI *et al.*, 2020).

The understanding about the effect of quality in yield evolved during the time, as Egli and Tekroni (1979) state that the main advantage to be obtained with the sowing of high vigor seeds was enhanced populations and not necessarily a gain in yield. On the other hand, Ellis (1992) affirmed that seed germination, vigor, and size (three aspects of quality of seeds) could indirectly or directly influence the yield. The indirect effects include those regarding the emergence percentage and the time between the sowing and the emergence. The author continues stating that until it can be quantified and, in the last stance, predict the direct and indirect effects of seed quality in the growth and yield of the crop, we have much to learn. Fortunately, this was a lesson learned. Nowadays, the scientific literature has many manuscripts showing a direct relationship between the quality of seeds and the yield of grain crops, following the approach that will be then presented.

Low vigor seeds can form an inadequate stand of plants because the seeds will present reduced germination and emergence speed, producing plants with a small initial size that generates lower dry material, lower leaf area, and reduced growth rate of plants. It can affect the establishment of the crop, its performance during the cycle and cause damages to the final economic yield (XAVIER *et al.*, 2020). For corn, the increase in the percentage of high vigor seeds in a determined lot enhances the initial growth until the eight leaves phase, increasing the height, stem diameter, and leaf area index of plants (MONDO *et al.*, 2013b).

The vigor of seeds is directly related to the initial growth of plants, and its effects may not persist until the end of the crop cycle if the field conditions in the initial stage are favorable. Nevertheless, when seed lots are used constituted by high and low vigor seeds (heterogeneous seed lots – in deterioration process), there will be higher intraspecific competition, which leads to a lower competitive capacity of plants originated from low vigor seeds. These plants are dominated by those that originated from high vigor seeds, which reflects negatively in the yield per plant (MONDO *et al.*, 2012).

These characteristics increase the competitive ability of plants and can have direct effects on corn grain yield. Heterogeneity of seed vigor affects the intraspecific competition in the crop populations, which results in losses in the concentration of dry matter, and the grain yield per area. The plants that originated from low vigor seeds have a lower competitive ability, low concentration of dry matter, and lower yield than those that originated from high vigor seeds due to the dominant effect. When this intraspecific competition is present, the main component of production affected by intraspecific competition is the number of grains per line (MONDO *et al.*, 2013a).

Researching sorghum (*Sorghum bicolor* L.), Camargo and Vaughan (1973) verified that the level of seed humidity is generally higher in the harvest season when seeds with lower vigor levels are used in the establishment of the crop. This finding indicates that the maturation process can be delayed due to low vigor. In this study, a combined treatment (seeds with distinct quality) presented similar results to those with more deteriorated seeds in many performance characteristics of the plant. This evidence shows that even small reductions in the quality of seeds result in a significant effect on the crop characteristics.

Due to its economic importance, being produced mainly in tropical regions with unfavorable storage conditions to maintain quality and morphologic characteristics, and its chemical composition, predominantly lipoprotein, contributes to deterioration, soybean has received more attention concerning the physiological quality of seeds.

High physiological potential seeds, especially with high vigor, can enhance the crop yield compared to the low vigor seeds. The implementation of soybean crops with low vigor seeds results in higher unevenness within the plant population and intraspecific competition, which, by its turn, influences negatively in yield (CANTARELLI *et al.*, 2015).

A classic study developed by Kolchinski *et al.* (2005) demonstrated that plants from high vigor seeds presented a higher index of leaf area, dry matter production, and seed yield but did not present dominant behavior on plants with low vigor adjacent in the sowing rows. Increases in the proportion of high vigor seeds in the establishment of communities of soy plants proportionated increases in the leaf area index, the production of dry matter, and the seed yield. According to the authors, the use of high vigor seeds increases seeds yield by more than 35% compared with low vigor seeds.

According to Ebone (2020), the vigor of seeds can affect the time necessary for plant emergence. Late emergence can reduce the stem diameter and increase the length of the internodes in the phenotypic adaptation, which generates a lower grain dry mass due to the reduction of fertile nodes. The author also emphasizes that soy plants with higher yields emerge more quickly, generally generating a more robust root system.

Population density and vigor of seeds affect the agronomic performance of different soy cultivars because it determines emergence speed and the establishment of seedlings in the field. Seeds with low vigor result in smaller plants with low height at the pod insertion and fewer pods per plant (ROSSI *et al.*, 2019).

The productive performance of soy plants increases as the vigor of the seed lots increases. For each percentage point increase in the vigor level of a soy seed lot (as evaluated by the accelerated aging test), the grain yield can increase up to 28,0 kg per hectare. The impact of the vigor of seeds on the physiological performance potential of a soybean crop depends on the plant genotype (BAGATELI *et al.*, 2019a; 2019b).

Similarly, it was verified by Henning *et al.* (2010), Scheeren *et al.* (2010), Caverzan *et al.* (2018), and Carvalho *et al.* (2020) that the use of high vigor seeds generates seedlings with a higher index of emergence speed and a higher rate of lot establishment, even in unfavorable sowing conditions. This fact permits a higher number of legumes per plant and a higher thousand-grain mass. On the other hand, crops obtained through low vigor seeds result in a lower plant stand and low tolerance to stress factors, such as water deficit and low yield (VANZOLINI; CARVALHO, 2002).

The use of high vigor seeds positively influences yield components of soybean crops, generating a higher mean number of productive nodes per plant, a higher total number of pods per plant, and consequently a higher number of seeds per plant, which results in yield gains of up to 19% compared with low vigor seeds (BAGATELI *et al.*, 2020).

High vigor seeds can provide a better establishment of plants and result in higher yield. High vigor seeds favor the physiological aspects of seeds. The use of high vigor seeds provided yield gains of 30% in soybean crops compared with seeds from low vigor lot; it contrasts with the yield increase reported by the research previously mentioned (CARNEIRO *et al.*, 2020).

In summary, **seedling vigor** is intrinsically related to crop yield. High vigor seeds tend to form better stands (especially under adverse conditions) and present better yield.

In common bean cultivation (*Phaseolus vulgaris* L.), Mondo *et al.* (2016) report that among the factors that affect the emergence of seedlings and the establishment of the crop are germination and vigor of seeds. Consequently, it affects the establishment of the plant population and their early development, affecting yield up to 20%. It is highlighted that, traditionally, common bean seed utilization rate is very low (ABRASEM, 2019), which permits us to infer that the physiological quality of the “grain” used as a seed is of low quality, certainly impacting significantly the volumes produced at a national level.

For wheat (*Triticum aestivum* L.), studies conducted by Abati *et al.* (2017) demonstrate that the use of high-quality seeds, good practices of management, and the selection of promising genotypes are strategies to explore the yield potential. The use of high vigor seeds aids the establishment of plant stand and the productive development of the crop.

The initial vigor of seeds and the sowing density interact in establishing the plants in the field. They can influence the plasticity expression of wheat crops, the yield, and the physiological quality of the seeds produced (CARDOSO *et al.*, 2021).

In wheat cultivation, it is frequently observed that the establishment of the number of plants per area is inferior to the number of viable seeds used, which may be related to the environmental conditions or the vigor of seeds. High vigor seeds favor the establishment of the stand, the growth and the development of plants in the initial phenological stages, and wheat grain yield (ABATI *et al.*, 2018).

It is important to mention that besides using high-quality seeds, adjusting an adequate sowing density is necessary. In this sense, it is not frequent to observe the number of plants established per area corresponding to the number of viable seeds used, which may be related to environmental conditions and the vigor of seeds; factors that receive minor consideration in wheat crop (BAGATELI, 2020).

Besides being considered a crop with lower economic importance, seed quality was also studied for rapeseed (*Brassica napus* L.). A study conducted by Ghassemi-Golezani *et al.* (2010) concluded that the number of grains per plant, thousand-grain mass, and the grain yield per plant for plants of deteriorated lots was higher than those of lots with high vigor seeds. Nevertheless, such advantages in individual plant performance were insufficient to establish low populations using low-quality seeds. Consequently, the grain yield by the unit of the area increased significantly with the increase of seed vigor.

Rice cultivation (*Oryza sativa* L.) in Brazil is predominantly conducted with flood irrigation. In the state of Rio Grande do Sul, the major rice producer in the country, sowing may start in the first fortnight of September. In some regions, rice farmers anticipate sowing so that the apex of solar radiation occurs during the reproductive stage of the plants. However, soil temperature may be exceedingly low due to the winter. Under such conditions, if low vigor seeds are used, a significant delay in emergence may occur, resulting in weak seedlings, where some do not survive, decreasing the cultivation stand, which may require the reseeding of some areas (XAVIER *et al.*, 2020, ARENHARDT, 2021).

Marcos Filho (2013) observed that, as the phenological stages of the cultivation advance, the influence of vigor of seeds tends to decrease, and the plant performance depends more on genotype-environment relations. Nevertheless, Melo *et al.* (2006) observed that rice plants from high vigor seeds presented higher tillering, dry mass, leaf area, and grain yield than low vigor seeds.

For this cultivation, the physiological quality of seeds affects the performance of mature plants. High vigor seeds generate plants with higher physiological potential, reflecting in higher growth and grain yield. Studies conducted by Mielezrski *et al.* (2008), Schuch *et al.* (2000) and Höfs *et al.* (2004) present that the physiological quality of seeds affects the development of mature plants when cultivated in isolation, showing more significant growth, higher levels in the grain yield components and yield 20% higher than plants generated by low vigor seeds.

Working with hybrid varieties of rice, plants obtained through high vigor seeds present better performance compared with those through low vigor seeds when individually evaluated for the parameters of leaf area, height, number of panicles per plant, number of grains per panicle, number of grains per plant, and grain yield, independently from the plant arrangement inside the population. Increases in the proportion of plants originating from high vigor seeds promote increases in crop yield and yield components. Communities of plants established with high vigor seeds present grain yield 20% higher than communities based on low vigor seeds (NEVES, 2010).

In cotton cultivation (*Gossypium hirsutum* L.), the quality of seeds is often neglected, being common the use of low vigor seeds or even with germination below the commercial standard, being necessary to adjust the plant population, increasing the seed density by linear meter. According to Mattioni *et al.* (2012), seed vigor can influence plant emergence, performance, and yield, depending on the species and the environmental conditions. A study conducted by the same researchers concluded that the initial and the reproductive development of cotton plants in field conditions depends, besides other factors, on the vigor level of seeds. When the initial development is maximized, plants with higher vigor are generated, and, by their turn, they present a higher yield of fibers and stones.

The importance of physiological quality of seeds for forages

With a cattle herd estimated at 213,68 million head in 2019, and an area of 162,53 million hectares occupied by pastures, Brazil stands among the leading producers and exporters of beef in the world (ABIEC, 2020). It is the second-largest producer, only behind the United States, and the largest exporter. In the last four decades, the country's herd more than doubled while the area occupied by pastures remained almost the same, reflecting the gains in yield and reinforcing the importance of the seeds used in this sector for the pastures. The main area destinated per year to the production of seeds of tropical forage plants was estimated to be 237 mil ha, between 2013 and 2017, with the higher concentration in the states of Minas Gerais, Bahia, Mato Grosso, Mato Grosso do Sul, Goiás, and São Paulo (LANDAU *et al.*, 2020). This production is responsible for the supply of the internal market and other Latin American countries (especially Mexico, Colombia, and Venezuela), Africa, and Asia (JANK *et al.*, 2014). Advancements have followed this scenario in the production systems of forage seeds, marked by higher technification and specialization of producers, who have offered high-quality seeds in the market, dominated by species of *Urochloa* spp. and *Panicum maximum* Jacq.

For most forage plants, there is an unevenness in the emission of inflorescence among plants of the same area or even in the same plant, which leads to unevenness in the maturation of seeds. Besides, the occurrence of natural dehiscence in these species is frequent. Both factors together provoke early harvests that result in seeds with low physiological quality, as there are still many immature seeds mixed with physiologically mature seeds in this stage. On the other hand, late harvests result in a reduction in yield because many seeds were already scattered due to natural dehiscence. Such factors led to adopting the harvest method of sweeping as the primary model for forage seeds. However, this method reduces the physical quality of lots as it favors the presence of contaminants, which are collected together with the seeds, such as rocks, soil particles, vegetable leftovers, and seeds of other species. Thus, besides the recognized importance of seed quality for pastures, in Brazil, lots with a high percentage of impurities and with low physiological and sanitary quality are predominant for commercializing (MARCHI *et al.*, 2010; TERNUS, 2017; CHORTASZKO *et al.*, 2019), besides the offer of seeds with unknown origin, which is produced informally.

Being perennial crops, fails while obtaining the stand or problems during the pasture establishment phase can have consequences for long periods compared with annual crops.

To enhance lot quality, many companies have adopted processing practices and pre-germinating treatments that, demonstrably, resulted in a significant increase in the physiological quality of seeds of forage plants. Although the goal is enhancing the physical quality of seed lots by removing empty spikelets, partially developed caryopsis, rocks, vegetable leftovers, and other species' seeds, the processing has also presented gains in the physiological quality of lots, as occurred with *Urochloa brizantha* (HESSEL *et al.*, 2012; JEROMINI, 2017), Guinea-grass (*Panicum maximum* cv. Mombasa) (MELO *et al.*, 2016), Massai grass (*Panicum maximum* cv. Massai) (MELO *et al.*, 2018), and Italian rye-grass (VERGARA *et al.*, 2019). It happens because are already removed lighter, immature, damaged, and deteriorated seeds during the process, which generally have a lower specific mass than seeds with higher physiological quality.

Moreover, treatments such as the covering and the osmopriming have presented promising results in seeds of forage plants, favoring speed and uniformity in germination and the emergence of seedlings. It results in more uniform stands with higher competitive capacity with unwanted plants during the establishment phase of pastures and a minor period between sowing and the first grazing. Seeds of species whose floral development is uneven, which is the case of many forage species, tend to benefit more from osmopriming treatments (FINCH-SAVAGE; BASSEL, 2016). Such treatments are recommended for high physiological quality seeds, as the treatments did not present consistent and economically viable responses for seeds already presenting some degree of deterioration. In this sense, osmopriming of *U. brizantha* seeds presented a higher radicle protrusion speed and uniformity in germination (BONOME *et al.*, 2006). Species of naturally occurring forage legumes, such as adesmia (*Adesmia latifolia* (Spreng.) Vog.), can also benefit from osmopriming, presenting higher germination speed and percentage, higher mean length and accumulation of dry matter in seedlings, whether in flower beds or under controlled conditions and favor the overcoming of seed dormancy (SUÑÉ *et al.*, 2002). Osmopriming effects are more evident when the seeds are under unfavorable environmental conditions during the sowing, such as water deficit, salinity, or extreme temperatures, which favors the expression of the vigor of treated seeds, as observed in *Urochloa brizantha* seeds, to which physiological priming reduced the harmful effects of water restriction and salinity (OLIVEIRA, 2020).

The results of seed covering of forage plants, including film coating, encrusting, or pelleting, strongly depend on the combination of the materials used to modify seed shape or size and negatively impact germination speed and seedling emergence. It occurs because they reduce the gas exchange between the seeds and the external environment, reducing oxygen availability or reduce the embryo expansion by forming an additional physical barrier represented by the material applied in the exterior seed layer. Adverse effects related to seed cover were already verified in *Urochloa brizantha* seeds, attributed to restrictions to the water inlet and outlet and the gas exchange caused by the presence of a layer covering the seeds treated (CÂMARA; STACCIARINI-SERAPHIN, 2002). It was also seen in hybrid seeds of *Brachiaria* (*B. brizantha* x *B. decumbens x B. ruzizienses*), whose covered seeds presented a reduction in viability, germination speed, germination, seedling emergence, and low activity of the enzyme α-amylase (FERREIRA *et al.*, 2015). Thus, seed companies have sought to associated covering treatments and osmopriming to compensate the possible damages to germination caused by covering without losing the advantages of covering, notedly, better plantability, better management, and incorporation of desirable active ingredients (phytosanitary products, growth regulators, and micronutrients). In seeds of *U. brizantha*, it was already demonstrated that osmopriming could reduce the adverse effects of seed pelleting in germinative development (BONOME *et al.*, 2017). *U. brizantha* seeds covering with magnesium thermophosphate and agricultural plaster enhanced the physiological quality of seeds and initial growth of plants (GUERREIRO, 2017). In the same manner, pearl millet seeds (*Pennisetum glaucum* (L.) R. Br.) pelleted using vermiculite and microcrystalline cellulose as a filling material, and polyvinyl acetate (PVA) and methylcellulose as adhesives, presented better physiological performance (PESKE; NOVEMBRE, 2011).

The recognition of the quality of seeds importance for pastures has led enhancement programs to adopt strategies to select plants that present a higher potential to produce high-quality seeds based not only on the phytomass potential and the nutritional value of the forage under grazing conditions.

The importance of physiological quality of seeds for vegetables

The industry of fruits and vegetables is directly related to about 13 million jobs, involving 3.3 million producers that grow at least 24 plant species in 5.1 million hectares in Brazil (CARVALHO *et al.*, 2019). In the last years, horticulture has moved around R$ 30 billion in the market, mainly producing potato (*Solanum tuberosum* L.), tomato (*Solanum lycopersicum* L.), onion (*Allium cepa* L.), cabbage (*Brassica oleracea* L. var. *capitata* L.), carrot (*Daucus carota* L.), and sweet potato (*Ipomoea batatas* (L.) Lam.). In 2018, horticulture alone offered 7 million direct or indirect jobs (KIST *et al.*, 2018). According to SENAR/CNA (2017), not even the price oscillations, high production costs, and climatic adversities that affected the major vegetable production regions in 2017 discouraged the producers. Producers keep their profit by enhancing management and using new technologies, such as protected cultivation and fertirrigation, which evidences the tendency to increase technification in the different stages of production. In this scenario, the availability of seedlings of well-known origin, healthy and vigorous, is fundamental to fulfill the growing demand of producers.

The uniformity of seedlings, by its turn, is directly related to the quality of seeds. High-quality seeds generate high germination levels and the emergence of seedlings that present well-formed aerial parts and roots within the standards expected by producers. On the other hand, low-quality seeds, especially regarding vigor, present problems already in the seedling emergence phase. In most cases, there is not enough time to make amendments for the failures in repicking and reseeding. Exceptionally, some nurseries make this option, which generates additional costs with employees and compromises planning and management. The effect of quality of seeds on the formation of seedlings is reported for many species in which it is generally observed that high physiological quality seeds produce seedlings with a higher number of leaves, height, root length, and phytomass, as presented for lettuce, *Lactuca sativa* L. (FRANZIN *et al.*, 2005), rocket, *Eruca sativa* L. (PÊGO *et al.*, 2011), and tomato (NASCIMENTO; PEREIRA, 2016). According to Marcos Filho (2005), the physiological potential of seeds indirectly influences the production under field conditions by affecting the emergence percentage and directly affecting the vigor of plants. For short-cycle vegetables, such as lettuce, this effect is even more pronounced because the harvest is performed during the vegetative cycle of plants.

In this scenario, it is worth mentioning the production costs of some vegetables, emphasizing the significant expenditures with seeds. For instance, a study conducted by the

Universidade de São Paulo – USP, in 2011, in the city of Mogi Guaçu, SP, about the tomato harvest of 2009 and 2010 reported that the expenditures with seeds represented almost 7% of the total production costs for each period; expenditures of nurseries in the same period were 0,5% and 0,7%, respectively. In the case of carrot production in the region of Triângulo Mineiro, costs with seeds in the summer harvest of 2009/10 and winter 2010 were 7,98% and 8,34%, respectively, and around 12% of the total cost for onion production in 2010 harvest in the same region (HORTIFRUTI BRASIL, 2011).

Thus, the preoccupation with the professionalization of nurseries is growing to turn them into recognized providers of seedlings with high genetic, physiological, and sanitary standards. It is extremely important to provide seeds with a good origin, high germination levels, and satisfying vigor to deal with this issue. This implies the use of lots with seeds of high physiological quality that provide uniform stands. Big seed companies have succeeded in providing the market with seeds attending such high-quality patterns. For instance, in 2000, according to the Associação Brasileira do Comércio de Sementes e Mudas (ABCSEM), the seed market had moved more than 26 million dollars and around 3.2 thousand tons of seeds. In 2009, the sector moved 76 million dollars, considering only the selling, by the thousands, of pelleted seeds of lettuce and hybrids of carrot, melon (*Cucumis melo* L.), bell pepper (*Capsicum annuum* L.), and tomato (JORGE *et al.*, 2016). In 2016, the market of seeds reached numbers higher than 0.7 billion reais, with a prominent role of tomato and onion seeds (PESKE, 2016).

Even before the emergence of the seedling, many metabolic processes have occurred in the seeds that will culminate in germination. Thus, vigorous seeds guarantee the obtention of seedlings that will become productive plants in field conditions. As already mentioned, the maximal physiological quality of seed regarding germination and vigor is directly related to the maximal possible accumulation of dry matter, defined as the point of the physiological maturity of seeds (GUIMARÃES, 2009). It is the ideal point for the harvest of seeds. Thus, when aiming to obtain high physiological quality seeds, harvest planning is a fundamental factor, as it should not be early not to take seeds that have not reached this level of maturation, nor be delayed, because some seeds will already be in deterioration process (VILLELA; PERES, 2004). After physiological maturity, a deterioration process begins in which seeds are susceptible to a series of physiological alterations that culminate in the depletion of reserves and, in critical cases, in the complete loss of viability. Marcos Filho (2005) highlights that it is hard to determine absolute maturity because it would only happen if all the seeds reached this point simultaneously, which does not occur in practice. Thus, some parameters can be used to analyze the seeds of a specific lot, guiding the harvest regarding humidity level, size, the quantity of dry matter, germination, and vigor, besides changes in the physical characteristics of fruits and seeds. Hence, for lettuce, it is recommended that the harvest occurs when 50% of the seeds reach maturity; for onion, when 10% of the umbels are exposed; for cauliflower (*Brassica oleracea* L. var. *botrytis* L.), when the seeds present a dark-brown or black color; for carrot, when the umbels present light-brown color; for pea (*Pisum sativum* L.), when the seeds present a 13-14% humidity level; for corn (*Zea mays* L.), when the black layer is formed, or the seeds reach a 30-33% humidity level; for bell pepper, when the fruits acquire the characteristic coloration of the variety; and, for cabbage, when the seeds present a dark or black color.

The harvest procedures and extraction and drying of seeds vary according to the species, and, in the case of vegetables, the seeds can be originated from dry fruits, such as lettuce, brassica (*Brassica* spp.), carrot, and onion; from fleshy fruits that can be submitted or not to drying before the extraction of seeds, such pepper (*Capsicum* spp.) and okra (*Abelmoschus esculentus* (L.) Moench); and from humid fleshy fruits, such as eggplant (*Solanum melongena* L.), bell pepper, tomato, and the Cucurbitaceae in general. The seed drying process can be performed as soon as the seeds are harvested. High humidity is the factor that most negatively influences the physiological quality of seed lots during storage (PESKE *et al.*, 2009). This process is particularly critical for seeds that develop inside fleshy fruits, as occurs with tomato and melon, because the humidity level of the seed does not reduce rapidly during the maturation, although they resist desiccation without losing its germinative capacity (WELBAUM; BRADFORD, 1990).

Once the seeds are harvested and dried, efforts should be directed to keep the quality of seeds during the storage period because this characteristic cannot be increased, even under adequate conditions (VILLELA; PERES, 2004). For air-proof containers, the moisture level of seeds, in the case of orthodox seeds that characterize the seeds of most vegetables, should be from 5 to 7% to reduce breathing activity and not compromise storage and posterior commercialization. Nascimento *et al.* (2012) suggest that for tomato seeds, considering medium-term storage periods (less than ten years), the temperature should be 4 ^{o}C, and for more extended periods -20 ^{o}C.

Regarding the enhancement of the quality of vegetable seed lots, the technique of physiological priming (*priming*, osmopriming, hydro-priming, or matrix-priming), according to Castro *et al.* (2004), permits seeds to germinate rapidly and uniformly. It works as if seeds went through an "invigorating" process, in which seeds with "slower" germination could reach the "faster" ones. This technique has been widely used for seeds of vegetables, with results varying according to the treatment used, the initial quality of the seeds, the species, and even the cultivar. There are many reports in the literature regarding the positive effect of osmopriming in the performance of vegetable seeds, suggesting gains in the medium term of germination and the emergence of seedlings, as observed with melon and pepper (CASTAÑARES; BOUZO, 2018; SAMARAH *et al.*, 2016). It also promotes increases in the size and phytomass of seedlings, as presented by Mavi *et al.* (2006) for tomato, and by Batista *et al.* (2015) for pepper, and improvements in germination and the percentage of vigorous plants, as observed with rocket (ALVES *et al.*, 2012). Moreover, osmopriming promotes gains in the percentage and speed of germination and the emergence of seedlings, as observed for carrot (PEREIRA *et al.*, 2008), among other examples. The treatment generally generates benefits for germination and the initial stages of plant development. Still, it does not extend to the fruit formation phase, as reported for eggplant, pepper, cucumber (*Cucumis sativus* L.), and melon seeds (PASSAM *et al.*, 1989; GURGEL JR. *et al.*, 2009; LIMA; MARCOS-FILHO, 2009), endive, *Cichorium endivia* L. (FERRAZ *et al.*, 2019), and cauliflower (MARCOS FILHO; KIKUTI, 2008). Generally, osmopriming effects are more pronounced when the seeds are submitted to unfavorable conditions of germination, as observed with eggplant, watermelon (*Citrullus lanatus* (Thunb.) Matsum et Nakai), melon, and tomato, for which the priming permitted higher germination under lower temperatures (NASCIMENTO, 2005). For tomato and onion seeds, osmopriming promoted fast germination under lower temperatures. The benefits of the treatment were perceived for tomato under field conditions, which results in higher emergence and development of seedlings and precocious maturity of the fruits, without interfering in the plant yield (ALI *et al.*, 1990).

There is evidence that the osmopriming of seeds of vegetables can partially reverse the effects of seed deterioration, as observed in pepper seeds submitted to controlled deterioration and afterward osmoprimed. Priming benefitted germination and enhanced the deteriorated vigor of seeds (FIALHO *et al.*, 2010). Asparagus seeds (*Asparagus officinalis* L.) of low physiological quality also benefitted from osmopriming, which generated gains in germination and vigor (BITTENCOURT *et al.*, 2005).

The association between osmopriming and seed cover has also been widely used in seeds of vegetables, incorporating nutrients, pesticides, fungicides, and growth regulators in the cover layer. As observed for most species of high economic interest, treatment success depends on the combination of the different products used, as the cover can inhibit germination due to the physical barrier imposed to the water inlet, the gas exchange, and embryo expansion. A study about the association between osmopriming and carrot seeds pelleting using a mix of microcrystalline cellulose and thin sand in equal volumes as a filling material, evaluating different action of materials as adhesives, reported that the best pelleting products were the Rhoximat and Opadry. The pelleted seeds presented a slight reduction in the percentage and speed of germination, which was counterbalanced by osmopriming (NASCIMENTO *et al.*, 2009).

The combined effects of matrix-priming and gibberellin (gibberellic acid) in the germination and the stand of bell pepper and tomato seeds resulted in an improvement of germination and emergence of seedlings, which reduced the mean period of germination by 2 and 3 days in the matrix-primed seeds (ANDREOLI; KHAN, 1999). According to the authors, the matrix-priming efficiently directed the enzymes induced by gibberellic acid to digest endosperm cells, favoring the development of embryos. Gibberellic acid in the osmopriming solution also benefitted bell pepper seeds, harvested in different maturation stages. The best results were obtained with seeds originated from fruits with 20 to 50% reddish coloration (ALBUQUERQUE *et al.*, 2009).

To guarantee the offer of high-quality vegetable seeds, significant progress can be obtained regarding the development of tests that aim to evaluate the physiological quality of seeds, especially vigor tests. In this sense, many studies in the literature present adequate methodologies for the execution of vigor tests in vegetable seeds. One of these methodologies is the adequation of the accelerated aging test exchanging water for saline solutions, as defended by Jianhua and McDonald (1996), with promising results for cucumber seeds (ABDO *et al.*, 2005), coriander (TUNES *et al.*, 2011), tomato (PANOBIANCO; MARCOS FILHO, 2001), carrot (RODO *et al.*, 2000), melon (TORRES; MARCOS-FILHO, 2003), rocket (FREITAS *et al.*, 2018), lettuce (FRANDOLOSO *et al.*, 2017), and okra (TORRES *et al.*, 2014). There is an expectation of standardization of the alternative methodology of accelerated aging test to evaluate vigor of vegetable seeds that present reduced size, including the test in ISTA and AOSA international manuals (HYATT; TEKRONY, 2008).

Some software associated with traditional tests directed to evaluating the physiological quality of vegetable seeds also represents an advancement that propitiates less subjective evaluations, fast and non-destructive, which are innovative tools for the internal control of the quality of seeds in companies. The application of these tools has been adequate for seeds of many species, such as bell pepper (DIAS *et al.*, 2014), lettuce (PEÑALOZA *et al.*, 2005), tomato (SILVA; CICERO, 2014), and cucumber (CHIQUITO *et al.*, 2012). In general, programs have been developed to evaluate the vigor of seeds based on the performance of seedlings by collecting and processing images that result in indices corresponding to the vigor of seedlings.

In some circumstances, the germination of seeds can be slow or irregular not by having low physiological quality but by the action of dormancy mechanisms, which slows germination. In such cases, dormancy can result from the impermeability of the tegument as occurs in seeds of green beans (*Phaseolus vulgaris* L.), pea, and okra. It occurs, for instance, by the presence of phenolic compounds, aldehyde, and tannin in the involucre of seeds that interferes in gas exchange, as occurs with seeds of beetroot (*Beta vulgaris* L.), lettuce, pumpkin (*Cucurbita* spp.), and celery (*Apium graveolens* L.). It also occurs by the mechanic restriction to the development of embryos, as occurs with lettuce, tomato, and cucumber, and by the action of inhibitors, or some hormonal imbalance (LOPES; NASCIMENTO, 2012). Besides being ruled by genetic factors, the development of seed dormancy results from the influence of environmental factors during maturation, such as photoperiod, relative humidity, and water availability (MARCOS FILHO, 2005). However, there are cases of relative dormancy, which represents the sensibility of seeds to fluctuations in environmental factors, as is the case of maxixe (*Cucumis anguria* L.), in which the white light exerts an inhibitory effect, and some lettuce varieties, which depend on light to germinate the so-called positive photoblastic seeds. According to Lopes and Nascimento (2012), there are cases of dormancy, as occurs with celery and carrot, in which the embryo does not complete its maturation until it detaches from the mother plant and the maturation of seeds occurs unevenly in the same plant. It is worth mentioning the case of lettuce, where there is the interaction of endogenous promoters and inhibitors with environmental factors. In this case, ethylene can interact with the light or gibberellins and promote germination at higher temperatures. To overcome seed dormancy, specific treatments are often necessary, such as washing seeds in running water before sowing, mechanical or chemical scarification, or the application of germination enhancers. In other situations, just storing seeds for short periods is enough to pass through the dormancy stage.

Final considerations

Identifying more appropriate areas to produce seeds with high physiological quality, incorporating seeds physiological quality, besides yield characteristics, resistance to the main biotic and abiotic stress factors for the genotypes developed in enhancement programs, improvement of methodologies to evaluate the physiological quality of seeds and their use by quality control programs of the major seed companies, and the constant evolution of normative demands that regulate seed production are some examples of the importance of the physiological quality of seeds for agriculture.

Many advancements were already achieved in seed science and technology. However, many challenges remain related to the need to understand more the biochemical and metabolic factors related to the physiological quality of seeds and their interaction with the production environment.

The use of high physiological quality seeds is a fundamental factor for the success of many agricultural enterprises. It contributes to the economic return wished by producers and the fulfilling of the growing demands in food, fibers, and biofuel production.

References

ABATI, J.; BRZEZINSKI, C.R.; FOLONI, J.S.S.; ZUCARELI, C. BASSOI, M.C.; HENNING, F.A. Seedling emergence and yield performance of wheat cultivars depending on seed vigor and sowing density **Journal of Seed Science**, 2017. http://dx.doi.org/10.1590/2317-1545v39n1171002

ABATI, J.; BRZEZINSKI, C.R.; ZUCARELI, C.; FOLONI, J.S.S.; HENNING, F.A. Growth and yield of wheat in response to seed vigor and sowing densities. **Revista Caatinga**, v.31, n.4, p.891–899, 2018. https://doi.org/10.1590/1983-21252018v31n411rc

ABDO, M.T.V.N.; PIMENTA, R.S.; PANOBIANCO, M.; VIEIRA, R.D. Testes de vigor para avaliação de sementes de pepino. **Revista Brasileira de Sementes**, v.27, n.1, p.195-198, 2005. https://dx.doi.org/10.1590/S0101-31222005000100025

ABIEC. **Beef Report 2020**. Perfil da Pecuária no Brasil. Disponível em: http://abiec.com.br/publicacoes/beef-report-2020/. Acesso em: 19 abr. 2021.

ABRASEM. **Relatório Anual 2019**. Disponível em: http://www.abrasem.com.br/wp-content/uploads/2019/12/Relato%CC%81rio_2019_PORT_WEB.pdf. Acesso em: 2 mai. 2021.

ALBUQUERQUE, K.S.; GUIMARÃES, R.M.; GOMES, L.A.A.; VIEIRA, A.R.; JÁCOME, M.F. Condicionamento osmótico e giberelina na qualidade fisiológica de sementes de pimentão colhidas em diferentes estádios de maturação. **Revista Brasileira de Sementes**, v.31, n.4, p.100-109, 2009. https://doi.org/10.1590/S0101-31222009000400012

ALI, A.V.; SOUZA MACHADO, V.; HAMILL, A.S. Osmoconditioning of tomato and onion seeds. **Scientia Horticulturae**, v.43, p.213-224, 1990. https://www.sciencedirect.com/science/article/abs/pii/030442389090093T

ALVES, J.; BARBOSA, R.M.; COSTA, D.S.; SÁ, M.E. Condicionamento osmótico e desempenho fisiológico de sementes de rúcula. **Biotemas**, v.25, n.1, p.171-176, 2012. https://doi.org/10.5007/2175-7925.2012v25n1p171

ANDREOLI, C.; KHAN, A.A. Matriconditioning integrated with gibberellic acid to hasten seed germination and improve stand establishment of pepper and tomato. **Pesquisa Agropecuária Brasileira**, v.34, n.10, p.1953-1958, 1999. https://dx.doi.org/10.1590/S0100-204X1999001000023

ARENHARDT, L.G. **Ácido giberélico associado ao tratamento fitossanitário no uso imediato e armazenado sobre a qualidade de sementes e desenvolvimento inicial de arroz**. 2021. Dissertação (Mestrado em Ciência e Tecnologia de Sementes) – Faculdade de Agronomia Eliseu Maciel, Universidade Federal de Pelotas, 2021.

BAGATELI, J. R.; DÖRR, C. S.; SCHUCH, L. O. B.; MENEGHELLO, G. E. Desempenho produtivo de plantas de soja originadas de lotes de sementes com níveis crescentes de vigor. **Journal of Seed Science**, v.41, n.2, p.151-159. 2019a. https://doi.org/10.1590/2317-1545v41n2199320

BAGATELI, J.R.; DÖRR, C.S.; SCHUCH, L.O.B.; MENEGHELLO, G.E. Productive performance of soybean plants originated from seed lots with increasing vigor levels. **Journal of Seed Science,** v.41, n.2, p.151-159, 2019b. http://dx.doi.org/10.1590/2317-1545v41n2199320

BAGATELI, JR.; FRANCO, J.J; MENEGHELLO, G.E.; VILLELA, F.A. Vigor de sementes e densidade populacional: reflexos na morfologia de plantas e produtividade da soja **Brazilian Journal of Development**, v.6, n.6, p.38686-38718, 2020. https://doi.org/10.34117/bjdv6n6-422

BAGATELI, J.R. **Vigor de sementes e desempenho em campo de plantas de trigo e soja.** 2020. Tese (Doutorado em Ciência e Tecnologia de Sementes) – Faculdade de Agronomia Eliseu Maciel, Universidade Federal de Pelotas, 2020.

BALBINOT, E.; LOPES, H.M. Efeitos do condicionamento fisiológico e da secagem na germinação e no vigor de sementes de cenoura. **Revista Brasileira de Sementes**, v.28, n.1, p.1-8, 2006. https://doi.org/10.1590/S0101-31222006000100001

BATISTA, T.B.; BINOTTI, F.F.S.; CARDOSO, E.D.; BARDIVIESSO, E.M.; COSTA, E. Aspectos fisiológicos e qualidade de mudas da pimenteira em resposta ao vigor e condicionamento das sementes. **Bragantia**, v.74, n.4, p.367-373, 2015. https://doi.org/10.1590/1678-4499.0133

BITTENCOURT, M.L.C.; DIAS, D.C.F.S.; DIAS, L.A.S.; ARAÚJO, E.F. Germination and vigour of primed asparagus seeds. **Scientia Agricola**, v.62, n.4, p.319-324, 2005. https://doi.org/10.1590/S0103-90162005000400003

BONOME, L.T.S.; GUIMARÃES, R.M.; OLIVEIRA, J.A.; ANDRADE, V.C.; CABRAL, P.S. Efeito do condicionamento osmótico em sementes de *Brachiaria brizantha* cv. Marandu. **Ciência e Agrotecnologia**, v.30, n.3, p.422-428, 2006. https://doi.org/10.1590/S1413-70542006000300006

BONOME, L.T.S.; GUIMARÃES, R.M.; OLIVEIRA, J.A.; DOUSSEAU, S. Osmoconditioning of *Urochloa brizantha* seeds to reduce pelleting negative effects. **Brazilian Journal of Agriculture**, v.92, n.2, p.87-100, 2017. Disponível em: http://www.revistadeagricultura.org.br/index.php/revistadeagricultura/article/view/3197/pdf_2808. Acesso em: 21 abr. 2021. https://doi.org/10.37856/bja.v92i2.3197

CÂMARA, H.H.L.L.; STACCIARINI-SERAPHIN, E. Germinação de sementes de *Brachiaria brizantha* cv. Marandu sob diferentes períodos de armazenamento e tratamento hormonal. **Pesquisa Agropecuária Tropical**, v.32, n.1, p.21-28, 2002. Disponível em: https://www.revistas.ufg.br/pat/article/view/2436. Acesso em: 26 abr. 2021

CAMARGO, C. P.; VAUGHAN, C. E. Effect of seed vigor on field performance and yield of grain sorghum (Sorghum bicolor (L) Moench). **Proceedings of the Association of Official Seed Analysts,** v.63, p.135–147, 1973. www.jstor.org/stable/23432505.

CANTARELLI, L.D.; SCHUCH, L.O.B.; TAVARES, L.C.; RUFINO, C.A. Variability of soybean plants originated from seeds with different physiological quality levels. **Acta Agronómica**, v.64, n.3, p.218-222, 2015. https://doi.org/10.15446/acag.v64n3.45511

CARDOSO, C.P.; BAZZO, MARINHO, J.H.B.; MARINHO, J.L.; ZUCARELI, C.; Effect of seed vigor and sowing densities on the yield and physiological potential of wheat seeds. **Journal of Seed Science**, v.43, e202143002, 2021. https://doi.org/10.1590/2317-1545v43241586

CARNEIRO, T.H.M., CAVALCANTE, A.G.; ANDRADE, G.A.V.; LIMA, N. J. C.; AQUINO, L. A. Efeito do vigor de sementes sobre as características fisiológicas e produtivas da soja. **Acta Iguazu**, v.9, n.2, p.122-133, 2020. https://doi.org/10.48075/actaiguaz.v9i2.23489

CARVALHO, C.; KIST, B.B; BELING, R.R. **Anuário Brasileiro de Horti&Fruti 2020**. Santa Cruz do Sul: Editora Gazeta Santa Cruz, 2019. 96 p.

CARVALHO, F.P.; STRAHL, M.A.; SCHOT, A.D.; MICHELON,C.J.; SILVEIRA JÚNIOR, F.S.; EGGERS ,H.S.; MOURA, M.B.; JUNGES, E. Desempenho agronômico de cultivares de soja com distintos níveis de vigor e cenários de semeadura. **Revista Científica Rural**, v.22, n.2, p.132-148. 2020. https://doi.org/10.30945/rcr-v22i2.3292

CAVERZAN, A.; GIACOMIN, R.; MÜLLER, M.; BIAZUS, C.; LÂNGARO, N.C.; CHAVARRIA, G. How does seed vigor affect soybean yield components? **Agronomy Journal**, v.110, n.4, p.1-10, 2018. https://acsess.onlinelibrary.wiley.com/doi/epdf/10.2134/agronj2017.11.0670

CASTAÑARES, J.L.; BOUZO, C.A. Effect of different priming treatments and priming durations on melon germination behavior under suboptimal conditions. **Open Agriculture**, v.3, p.386–392, 2018. https://doi.org/10.1515/opag-2018-0043

CASTRO, R.D.; BRADFORD, K.J.; HILHORST, H.W.M. Desenvolvimento de sementes e conteúdo de água. *In*: FERREIRA, G. F.; BORGUESI, F. **Germinação**: do básico ao aplicado. Porto Alegre: Artmed, 2004.

CHIQUITO, A.A.; GOMES JUNIOR, F.G.; MARCOS FILHO, J. Assessment of physiological potential of cucumber seeds using the software Seedling Vigor Imaging System® (SVIS®). **Revista Brasileira de Sementes**, v.34, n.2, p.255-263, 2012. https://doi.org/10.1590/S0101-31222012000200010

CHORTASZKO, N.G.; SANTOS, P.R.; GARCIA, C.; MARTINICHEM, D.; FARIA, C.M.D.R. Avaliação da qualidade fitossanitária e germinação de sementes forrageiras. **Applied Research & Agrotechnology**, v.12, n.2, p.81-88, 2019.

DIAS, M.A.N.; MONDO, V.H.V.; CICERO, S.M. Recent approaches for bell pepper seed vigor testing. Acta Scientiarum, v.36, n.4, p.483-487, 2014. https://doi.org/10.4025/actasciagron.v36i4.18348

EBONE, L.A. **Vigor de sementes de soja: características de raízes, crescimento vegetativo e rendimento de grãos**. 2020. Dissertação (Mestrado em Agronomia) – Universidade de Passo Fundo, 2020.

EGLI, D.B.; TEKRONY, D.M., Relationship between soybean seed vigor and yield. **Agronomy Journal,** v.71, p.755-759, 1979. https://doi.org/10.2134/agronj1979.00021962007100050012x

ELLIS, R.H. Seed and seedling vigour in relation to crop growth and yield. **Plant Growth Regulation**, v.11, p.249–255, 1992. https://doi.org/10.1007/BF00024563

FERRAZ, A.; SILVA, V.N.; RADUNZ, A.L. Condicionamento fisiológico de sementes de chicória com *Ascophyllum nodosum*. **Revista Cultura Agronômica**, v.28, n.2, p.215-226, 2019. https://ojs.unesp.br/index.php/rculturaagronomica/article/view/2446-8355.2019v28n2p215-226

FERREIRA, V.F.; FERREIRA, T.F.; CARVALHO, R.A.; MAVAIEIE, D.P.R.; PEREIRA, D.S.; OLIVEIRA, J.A. Qualidade fisiológica de sementes revestidas de braquiária híbrida cv. Mulato II. **Revista Agro@ambiente On-line**, v.9, n.2, p.161-166, 2015. https://doi.org/10.18227/1982-8470ragro.v9i2.2471

FIALHO, G.S., SILVA, C.A.; DIAS, D.C.F.S.; ALVARENGA, E.M.; BARROS, W.S. Osmocondicionamento em sementes de pimenta 'amarela comprida' (*Capsicum annuum* L.) submetidas à deterioração controlada. **Ciência e Agrotecnologia**, v.34, n.3, p.646-652, 2010. https://doi.org/10.1590/S1413-70542010000300017

FINCH-SAVAGE, W.E.; BASSEL, G.W. Seed vigour and crop establishment: extending performance beyond adaptation. **Journal of Experimental Botany**, v.67, n.3, p.567-591, 2016. https://doi.org/10.1093/jxb/erv490

FRANDOLOSO, D.C.L.; RODRIGUES, D.B.; ROSA, T.D.; ALMEIDA, A.S.; SOARES, V.N.; BRUNES, A.P.; TUNES, L.V.M. Qualidade de sementes de alface avaliada pelo teste de envelhecimento acelerado. Revista de Ciências Agrárias, v.40, n.4, p.703-713, 2017. https://doi.org/10.19084/rca17009

FREITAS, R.M.O.; NOGUEIRA, N.W.; TORRES, S.B.; LEITE, T.S. Accelerated aging of arugula seeds. **Revista Brasileira de Ciências Agrárias**, v.13, n.4, e5585, 2018. https://doi.org/10.5039/agraria.v13i4a5585

GHASSEMI-GOLEZANI, K.; BAKHSHY, J.; RAEY, Y.; HOSSAINZADEH-MAHOOTCHY A. Seed vigor and field performance of winter oilseed rape (*Brassica napus* L.). **Cultivars Notulae Botanicae Horti Agrobotanici**, v.38, n.3, p.146-150, 2010.

GUERREIRO, D. **Revestimento na qualidade fisiológica de sementes e no desenvolvimento inicial das plantas de *Brachiaria brizantha***. 2017. Dissertação (Mestrado em Agronomia) – Faculdade de Agronomia e Medicina Veterinária, Universidade de Brasília, 2017.

GUIMARÃES, R.M. **Fisiologia de Sementes**. Lavras: UFLA/FAEPE, 129p. 1999.GURGEL JÚNIOR, F.E.; TORRES, S.B.; OLIVEIRA, F.N.; NUNES, T.A. Condicionamento fisiológico em sementes de pepino. **Revista Caatinga**, v.22, n.4, p.163-168, 2009.

https://periodicos.ufersa.edu.br/index.php/caatinga/article/view/1502/pdf

HENNING, F.A., MERTZ, L.M.; JACOB JR., E.A.; MACHADO, R.D.; FISS, G.; ZIMMER, P.D. Chemical composition and reserve mobilization in soybean seeds with high and low vigor. **Bragantia**, v.69, p.727–734, 2010. http://dx.doi.org/10.1590/S0006-87052010000300026

HESSEL, C.L.E.; VILLELA, F.A.; AUMONDE, T.Z.; PEDÓ, T. Mesa densimétrica e qualidade fisiológica de sementes de brachiária. **Informativo ABRATES**, v.22, n.3, p.73-76, 2012.

HÖFS, A.; SCHUCH, L.O.B.; PESKE, S.T.; BARROS, A.C.S.A. Efeito da qualidade fisiológica das sementes e da densidade de semeadura sobre o rendimento de grãos e qualidade industrial em arroz. **Revista Brasileira de Sementes**, v.26, n.2, p.55-62, 2004. https://doi.org/10.1590/S0101-31222004000200008

HORTIFRUTI BRASIL. Edição especial. Ano 10, n.102, 2011.

HYATT, J.E.; TEKRONY, D.M. Factors influencing the saturated salt accelerated aging test in tomato and onion. **Seed Science and Technology**, v.36, n.3, p.534-545, 2008. https://doi.org/10.15258/sst.2008.36.3.03

JANK, L.; BARRIOS, S.C.; VALLE, C.B.; SIMEÃO, R.M.; ALVES, G.F. The value of improved pastures to Brazilian beef production. **Crop and Pasture Science**, v.65, n.11, p.1132-1137, 2014. https://doi.org/10.1071/cp13319

JEROMINI, T.S. **Etapas de beneficiamento na qualidade física, fisiológica e sanitária de sementes de *Brachiaria brizantha***. 2017. Dissertação (Mestrado em Agronomia – Produção Vegetal) – Faculdade de Ciências Agrárias e Veterinárias, Universidade Estadual Paulista, 2017.

JIANHUA, Z.; McDONALD, M.B. The saturated salt accelerated aging test for small-seeded crops. **Seed Science and Technology**, v.25, n.1, p.123-131, 1996.

JORGE, M. H. A.; ANDRADE, J. A.; COSTA, E. O mercado de mudas de hortaliças. *In*: NASCIMENTO, W.M.; PEREIRA, R.B. **Produção de mudas de hortaliças**. Brasília-DF: Embrapa, 2016.

KIKUTI, A.L.P., KIKUTI, H.; MINAMI, K. Condicionamento fisiológico de sementes de pimentão. **Revista Ciência Agronômica**, v.36, n.2, p.243-248, 2005. http://ccarevista.ufc.br/seer/index.php/ccarevista/article/view/270.

KIST, B.B.; SANTOS, C.E.; CARVALHO, C.; BELING, R.D. **Anuário Brasileiro de Horti&Fruti 2019**. Santa Cruz do Sul: Editora Gazeta Santa Cruz, 2018. 96 p.

KOLCHINSKI, E.M.; SCHUCH, L.O.B.; PESKE, S.T. Vigor de sementes e competição intra-específica em soja. **Ciência Rural**, v.35, n.6, p.1248-1256, 2005. https://doi.org/10.1590/S0103-84782005000600004

LANDAU, E.C.; SIMEÃO, R.M.; MATOS NETO, F.C. Evolução da área ocupada por pastagens. *In*: LANDAU, E.C.; SILVA, G.A.; MOURA, L.; HIRSCH, A.; GUIMARÃES, D.P. **Dinâmica da produção agropecuária e da paisagem natural no Brasil nas últimas décadas**: produtos de origem animal e da silvicultura. Brasília, DF: Embrapa, 2020. v.3, cap. 46, p.1555-1578.

LIMA, L.B.; MARCOS FILHO, J. Condicionamento fisiológico de sementes de pepino e relação com desempenho das plantas em campo. **Revista Brasileira de Sementes**, v.31, n.3, p.27-37, 2009. https://doi.org/10.1590/S0101-31222009000300003

LOPES, A.C.A.; NASCIMENTO, W.M. **Dormência em sementes de hortaliças**. Brasília: Embrapa, 2012. 28p. (Documentos/Embrapa Hortaliças: 136).

MARCHI, C.E.; FERNANDES, C.D.; BUENO, M.L.; BATISTA, M.V.; FABRIS, L.R. Fungos veiculados por sementes comerciais de braquiária. **Arquivos do Instituto Biológico**, v.77, n.1, p.65-73, 2010. https://doi.org/10.1590/1808-1657v77p0652010

MARCOS FILHO, J. **Fisiologia de sementes de plantas cultivadas**. Piracicaba: FEALQ. v.12. 495p. 2005.

MARCOS FILHO, J. Importância do potencial fisiológico da semente de soja. **Informativo ABRATES**, v.23, n.1, p.21-24, 2013.

MARCOS FILHO, J.; KIKUTI, A.L.P. Condicionamento fisiológico de sementes de couve-flor e desempenho das plantas em campo. **Horticultura Brasileira**, v.26, n.2, p.165-169, 2008. https://doi.org/10.1590/S0102-05362008000200007

MATTIONI, F.; M.C. DE F.; MARCOS-FILHO, J.; GUIMARÃES, S.C. Vigor de sementes e desempenho agronômico de plantas de algodão**.** **Revista Brasileira de Sementes**, v.34, n.1 p.108 - 116, 2012. https://doi.org/10.1590/S0101-31222012000100014

MAVI, K.; ERMIS, S.; DEMIR, I. The effect of priming on tomato rootstock seeds in relation to seedling growth. **Asian Journal of Plant Sciences**, v.5, n.6, p.940-947, 2006. https://docsdrive.com/pdfs/ansinet/ajps/2006/940-947.pdf

MELO, L.F.; MARTINS, C.C.; SILVA, G.Z.; BONETI, J.E.B.; VIEIRA, R.D. Beneficiamento na qualidade física e fisiológica de sementes de capim-mombaça. **Revista Ciência Agronômica**, v.47, n.4, p.667-674, 2016. Disponível em: http://www.ccarevista.ufc.br/seer/index.php/ccarevista/article/view/4580/1470. Acesso em: 23 abr. 2021

MELO, L.F.; MARTINS, C.C.; SILVA, G.Z.; PEREIRA, F.E.C.B.; JEROMINI, T.S. Effects of processing phases on the quality of massai grass seeds. **Revista Ciência Agronômica**, v.49, n.2, p.259-266, 2018. https://doi.org/10.5935/1806-6690.20180029

MELO, P.T.B.S.; SCHUCH, L.O.B.; ASSIS, F.N; CONCENÇO, G. Comportamento individual de plantas originadas de sementes com diferentes níveis de qualidade fisiológica em populações de arroz irrigado. **Revista Brasileira de Sementes**, v.28, n.2, p.84-94, 2006. https://doi.org/10.1590/S0101-31222006000200011

MIELEZRSKI, F.; SCHUCH, L.O.B.; PESKE, S.T.; PANOZZO, L.E.; PESKE, F.B.; CARVALHO, R.R. Desempenho individual e de populações de plantas de arroz híbrido em função da qualidade fisiológica das sementes. **Revista Brasileira de Sementes,** v.30, p.86-94, 2008. https://doi.org/10.1590/S0101-31222008000300012

MONDO, V.H.V.; NASCENTE, A.S.; CARDOSO NETO, M.O. Common bean seed vigor affecting crop grain yield. **Journal of Seed Science**, v.38, n.4, p.365-370, 2016. http://dx.doi.org/10.1590/2317-1545v38n4166814

MONDO, V.H.V.; CICERO, S.M.; DOURADO-NETO, D.; PUPIM, T.L; DIAS, M.A.N. Effect of seed vigor on intraspecific competition and grain yield in maize. **Agronomy Journal**, v.105, n.1, p.222-228, 2013a. https://dl.sciencesocieties.org/publications/aj/abstracts/105/1/222

MONDO, V.H.V.; CICERO, S.M.; DOURADO-NETO, D.; PUPIM, T.L.; DIAS, M.A.N. Seed vigor and initial growth of corn crop. **Journal of Seed Science**, v.35, n.1, p.64-69, 2013b. https://doi.org/10.1590/S2317-15372013000100009

MONDO, V.H.V.; CICERO, S.M.; DOURADO-NETO, D.; PUPIM, T.L.; DIAS, M.A.N. Vigor de sementes e desempenho de plantas de milho. **Revista Brasileira de Sementes**, v.34, n.1, p.143-155, 2012. https://doi.org/10.1590/S0101-31222012000100018

NASCIMENTO, W.M. Condicionamento osmótico de sementes de hortaliças visando a germinação em condições de temperaturas baixas. **Horticultura Brasileira**, v.23, n.2, p.211-214, 2005. https://doi.org/10.1590/S0102-05362005000200010

NASCIMENTO, W.M.; MELO, P.C.T.; FREITAS, R.A. Produção de sementes. *In*: CLEMENTE, F. M. V.; BOITEUX, L. S. **Produção de tomate para processamento industrial**. Brasília-DF: Embrapa, 2012.

NASCIMENTO; W.M.; PEREIRA, R.B. **Produção de mudas de hortaliças**. Brasília: Embrapa, 2016. 308 p.

NASCIMENTO, W.M.; SILVA, J.B.C.; SANTOS, P.E.C.; CARMONA, R. Germinação de sementes de cenoura osmoticamente condicionadas e peletizadas com diversos ingredientes. **Horticultura Brasileira**, v.27, n.1, p.12-16, 2009. https://doi.org/10.1590/S0102-05362009000100003

NEVES, M.B. **Desempenho de individual e de populações de arroz híbrido relacionado a densidade populacional e ao vigor das sementes**. 2010. Dissertação. (Mestrado em Ciência e Tecnologia de Sementes) – Faculdade de Agronomia Eliseu Maciel, Universidade Federal de Pelotas, 2010.

OLIVEIRA, T.F. **Condicionamento fisiológico de sementes de *Urochloa* spp**. 2020. Tese (Doutorado em Agronomia/Fitotecnia) – Universidade Federal de Lavras, 2020.

PANOBIANCO, M.; MARCOS FILHO, J. Envelhecimento acelerado e deterioração controlada em sementes de tomate. **Scientia Agricola**, v.58, n.3, p.525-531, 2001. https://doi.org/10.1590/S0103-90162001000300014

PASSAM, H.C.; KARAVITES, P.I.; PAPANDREOU, A.A.; THANOS, C.A.; GEORGHIOU, K. Osmoconditioning of seeds in relation to growth and fruit yield of aubergine, pepper, cucumber and melon in unheated greenhouse cultivation. **Scientia Horticulturae**, v.38, n.3, p.207-216, 1989. https://www.sciencedirect.com/science/article/abs/pii/0304423889900678

PEÑALOZA, P.; RAMIREZ-ROSALES, G.; McDONALD, M.B.; BENNETT, M.A. Lettuce (*Lactuca sativa* L.) seed quality evaluation using seed physical attributes, saturated salt accelerated aging and the seed vigour imaging system. **Electronic Journal of Biotechnology**, v.8, n.3, p.299-307, 2005. https://doi.org/10.2225/vol8-issue3-fulltext-11

PEREIRA, M.D.; DIAS, D.C.F.S.; DIAS, L.A.S.; ARAÚJO, E.F. Germinação e vigor de sementes de cenoura osmocondicionadas em papel umedecido e solução aerada. **Revista Brasileira de Sementes**, v.30, n.2, p.137-145, 2008. https://doi.org/10.1590/S0101-31222008000200017

PEREIRA, C.E.; OLIVEIRA, J.A.; ROSA, M.C.M.; KIKUTI, A.L.P. Armazenamento de sementes de braquiária peletizadas e tratadas com fungicida e inseticida. **Ciência Rural**, v.41, n.12, p.2060-2065, 2011. https://doi.org/10.1590/S0103-84782011001200004

PESKE, S.T. O mercado de sementes no Brasil. **SeedNews**, ed. XX, 2016. Disponível em: https://seednews.com.br/artigos/546-o-mercado-de-sementes-no-brasil-edicao-maio-2016. Acesso em: 4 mai. 2021.

PESKE, F.B.; NOVEMBRE, A.D.L.C. Pearl millet seed pelleting. **Revista Brasileira de Sementes**, v.33, n.2, p.352-362, 2011. https://doi.org/10.1590/S0101-31222011000200018

PESKE, S.T.; VILLELA, F.A.; LABBÉ-BAUDET, L. Secagem de sementes de hortaliças. *In*: Nascimento, W.M. **Tecnologia de sementes de hortaliças**. Brasília: Embrapa Hortaliças, 2009.

RODO, A.B.; PANOBIANCO, M.; MARCOS FILHO, J. Metodologia alternativa do teste de envelhecimento acelerado para sementes de cenoura. **Scientia Agricola**, v.57, n.2, p.289-292, 2000. https://doi.org/10.1590/S0103-90162000000200015

SAMARAH, N.H.; WANG, H.; WELBAUM, G.E. Pepper (*Capsicum annuum*) seed germination and vigour following nanochitin, chitosan or hydropriming treatments. **Seed Science &Technology**, v.44, n.3, p.1-15, 2016. http://doi.org/10.15258/sst.2016.44.3.18

SCHEEREN, B.R; PESKE, S.T.; SCHUCH, L.O.B.; BARROS, A.C.S.A. Physiological quality of soybean seeds and productivity. **Revista Brasileira de Sementes**, v.32, n.3, p.35-41, 2010. https://doi.org/10.1590/S0101-31222010000300004

SILVA, V.N.; CICERO, S.M. Image seedling analysis to evaluate tomato seed physiological potential. **Revista Ciência Agronômica**, v.45, n.2, p.327-334, 2014. https://doi.org/10.1590/S1806-66902014000200014

SCHUCH, L.O.B.; NEDEL, J.L.; ASSIS, F.N.; MAIA, M.S.; ROSENTHAL, M.D. Emergência no campo e crescimento inicial de aveia preta em resposta ao vigor das sementes. **Revista Brasileira de Agrociência**, v.6, n.2, p.97-101, 2000.

SUÑÉ, A.D.; FRANKE, L.B.; SAMPAIO, T.G. Efeitos do condicionamento osmótico na qualidade fisiológica de sementes de *Adesmia latifolia* (Spreng.) Vog. **Revista Brasileira de Sementes**, v.24, n.1, p.18-23, 2002. https://doi.org/10.1590/S0101-31222002000100004

TERNUS, R.M. **Avaliação dos resultados de qualidade de sementes obtidos na execução do controle externo, no Estado de Santa Catarina (2013-2015)**. 2017. Tese (Doutorado em Ciência e Tecnologia de Sementes) – Faculdade de Agronomia Eliseu Maciel, Universidade Federal de Pelotas, 2017.

TORRES, S.B.; MARCOS FILHO, J. Accelerated aging of melon seeds. **Scientia Agricola**, v.60, n.1, p.77-82, 2003. https://doi.org/10.1590/S0103-90162003000100012

TORRES, S.B.; SILVA, F.G.; GOMES, M.D.A.; BENEDITO, C.P.; ELDER, F.; PEREIRA, C.B.; SILVA, E.C. Diferenciação de lotes de sementes de quiabo pelo teste de envelhecimento acelerado. **Ciência Rural**, v.44, n.12, p.2103-2110, 2014. https://doi.org/10.1590/0103-8478cr20120886

TUNES, L.M.; PEDROSO, D.C.; BARBIERI, A.P.P.; CONCEIÇÃO, G.M.; ROETHING, E.; MUNIZ, M.F.B. Envelhecimento acelerado modificado para sementes de coentro (*Coriandrum sativum* L.) e sua correlação com outros testes de vigor. **Revista Brasileira de Biociências**, v.9, n.1, p.12-17, 2011. Disponível em: http://www.ufrgs.br/seerbio/ojs/index.php/rbb/article/view/1645. Acesso em: 11 mai. 2021

VANZOLINI, S.; CARVALHO, N.M. Efeito do vigor de sementes de soja sobre o seu desempenho em campo. **Revista Brasileira de Sementes**, v. 24, n.1, p.33- 41, 2002. https://doi.org/10.1590/S0101-31222002000100006

VERGARA, R.O.; ARAÚJO, A.S.; NADAL, A.P.; BRUNES, A.P.; CARVALHO, I.R.; GADOTTI, G.I. Uso da mesa densimérica no beneficiamento de sementes de azevém. **Colloquium Agrariae**, v.15, n.4, p.82-89, 2019. https://doi.org/10.5747/ca.2019.v15.n4.a314

VILLELA, F.A.; PERES, W.B. Coleta, beneficiamento e armazenamento. *In*: FERREIRA, G. F.; BORGUESI, F. **Germinação**: do básico ao aplicado. Porto Alegre: Artmed, 2004.

WELBAUM, G.E.; BRADFORD, K.J. Water relations of seed development and germination in muskmelon (*Cucumis melo* L.). III. Sensitivity of germination to water potential and abscisic acid during development. **Plant Physiology**, v.92, n.4, p.1029-1037, 1990. https://doi.org/10.1104/pp.92.4.1029

XAVIER, F.M.; ARENHARDT, L.G.; MENEGHELLO, G.E. Vigor de sementes no desempenho agronômico da cultura do arroz. **SeedNews**, v.24, n.5, p.17-22, 2020.