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CROP PRODUCTION

Bibliometric revision regarding the use of survival analysis in seed germination studies

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ABSTRACT: Studies on seed science are developed for a wide range of purposes, being the statistical analysis of data essential for experimental reliability and evidence. Due to the characteristics of seed data, several statistical methods can be applied, among them the survival analysis stands out, in virtue of allocating censored data and describing phenomena over time. Therefore, this bibliometric study verified the use of survival analysis in studies with seed germination and to examine the applications of survival analysis in original articles from the Web of Science database for the period from 2000 to 2020. For the application of survival analysis, there was a low number of publications related to seed science, with the USA being the country with the highest number of publications mainly to studies in plant ecology and physiology. In general, the researches were most involved to the evaluation of factors influencing dormancy, physiological stresses, dispersion capacity, population differences and habitats of development which affected seed germination. Therefore, the qualitative overview demonstrates that the survival analysis is a statistical tool of great potential regarding the studies in the area.
Key words: censoring, germination data, seed technology, time-to-event analysis.

Revisão bibliométrica sobre o uso da análise de sobrevivência em estudos com germinação de sementes

RESUMO: Estudos em ciência de sementes são desenvolvidos frente a uma ampla gama de finalidades, sendo a análise estatística dos dados um componente imprescindível para confiabilidade e comprovação experimental. Devido às características dos dados de sementes, diversos métodos estatísticos podem ser aplicados na sua análise, dentre os quais destaca-se a análise de sobrevivência, em virtude de alocar dados censurados e descrever fenômenos ao longo do tempo. Sendo assim, este estudo bibliométrico teve por objetivo verificar o uso da análise de sobrevivência em estudos com germinação de sementes e examinar as aplicações da análise de sobrevivência em artigos originais da base de dados Web of Science para o período de 2000 a 2020. Observou-se para aplicação da análise de sobrevivência, baixo número de publicações com este método estatístico ao decorrer dos anos, sendo os Estados Unidos (EUA) o país de maior produtividade em publicações, com pesquisas relacionadas principalmente a estudos em ecologia vegetal e fisiologia. Em geral, as pesquisas foram mais voltadas para a avaliação de fatores que influenciam a dormência, estresses fisiológicos, capacidade de dispersão, diferenças populacionais e habitats de desenvolvimento que afetaram a germinação das sementes. Portanto, o panorama qualitativo demonstra que a análise de sobrevivência é uma ferramenta estatística de grande potencial em relação aos estudos na área.
Palavras-chave: censura, dados de germinação, tecnologia de sementes, análise do tempo até o evento.

INTRODUCTION

Studies on seed science are developed for a wide variety of goals that permeate plant science, as the example of phytotechnics, ecology, genetics, and management of weeds, in which variables such as: time, uniformity, speed and germination synchrony are considered, besides final germination (RANAL & SANTANA, 2006).

About the statistical methods that can be applied to analyze the phenomenon of germination, there is an extensive collection, as well as bibliographic reviews, approaching different statistical methods, among which are, for example, analysis of variance (ANOVA) followed by the application of means tests, classical regression methods, non-parametric tests, generalized linear models, and survival analysis (SCOTT et al., 1984; PYKE & THOMPSON, 1986; RANAL & SANTANA, 2006; ROMANO et al., 2018; ROMANO & STEVANATO, 2020).

It is important to point out that the most appropriate statistical method for the study of a given phenomenon is related to the objectives of the analysis, the type of variable involved in the study, as well as characteristics of data. In this context, since germination is one of the agricultural processes

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that is intrinsically associated with time, the use of methodologies capable of better describing this process should be considered.

Among these methodologies, survival analysis is a branch of Statistics that encompasses a set of models and methods characterized by presenting as response variable the time until an event of interest occurs (BOTELHO et al., 2009), this being an intrinsic variable to the phenomenon of germination. In this scenario, in survival analysis, when the event of interest occurs within the period stipulated in the analysis, the concept of failure is verified (COLOSIMO & GIOLO, 2006). In addition to the concept of failure, survival analysis presenting as characteristic the allocation of censored data, in other words, partial observations of the response, for the estimation of variables of interest (COLOSIMO & GIOLO, 2006).

Censored data are defined as observations which did not present the event of interest, in the period under study; therefore, even being characterized as incomplete data. Germination data, in general, are subject to causes of censoring, such as not viable seeds and dormant seeds, which lead the observation unit not to present the event of interest in the studied period (interval censoring), seeds that have not germinated until the end of the experiment (left censoring) or seeds that germinate before the first evaluation (right censoring) (ONOFRI et al., 2011). The survival analysis, by incorporating censored data, provide relevant information regarding the time of occurrence of the previously fixed event, reducing the determination of biased conclusions (SZKLO & NIETO, 2000) and allowing a greater gain of information and pertinent interpretations.

Given this organization, the survival analysis can be used for studies involving seed germination, since this is an event associated with time and germination can be characterized as a qualitative process of binary result, in which 1 corresponds to the occurrence of the germination process (failure) and 0 to the absence of this event (censoring) (CARDOSO, 2009), being very convenient to the survival analysis methods (ADEGBOLA & PÉREZ, 2016; SOLARIK et al., 2016; GENNA & PÉREZ, 2016; PÉREZ & KANE, 2017; BARAK et al., 2018). In this way, it is verified the relevance of productions that aim to present applications and functionalities of survival analysis on seed science.

Therefore, the present study was performed aiming the quantitative evaluation of the survival analysis in scientific production involving studies with seed germination. Qualitatively it was examined the applications of the survival analysis in these studies by a bibliometric study, seeking to highlight the potential of this analysis in studies involving seed germination, given that survival analysis methods are powerful, flexible and statistically robust for seed science data, but still little applied in the plant literature.

DEVELOPMENT

Data Source

Data collection was performed based on the main collection of the database of the Web of Science platform, which encompasses the main academic periodicals, books and annals referring to the world scientific production (providing access to six citation databases: *Science Citation Index Expanded* – SCI-EXPANDED, *Social Sciences Citation Index* – SSCI, *Arts & Humanities Citation Index* – A&HCI, *Conference Proceedings Citation Index-Science* – CPCI-S, *Conference Proceedings Citation Index-Social Science & Humanities* – CPCI-SSH and *Emerging Sources Citation Index* – ESCI). The study was performed regarding the period from 2000 to 2020, since it is observed a higher frequency of the use of survival analysis in studies on seed science from the year 2000 onwards, added to the fact that restriction of the period allows a more detailed qualitative analysis of the scientific productions.

Search Strategy

As the criterion for the selection of the contents, one search term was established, directed to the survival analysis in seed germination studies. Regarding the selection of reports for the survival analysis, the search terms "*survival analysis" and "germination"* were selected. The truncation operator "quotes" (") limits the search for terms that are adjacent in the text, fixing the sequence, in this order, and without any other word for the expression of interest. Furthermore, the boolean logical operator "*and"* was applied in the composition of the search terms, which allows the combination of two terms, in this case, "*survival analysis"* and *"germination"*.

Given this structuring, 45 publications were obtained regarding the survival analysis. Following the methodology usually employed in bibliometric studies, the search was restricted to original articles published in periodicals, excluding review articles and annals of scientific meetings, since the peer review criteria adopted for the publication of original scientific articles result in great reliability regarding experimental method, reproducibility,

and significance. Thus, for the survival analysis, 41 articles were initially selected. Each of the articles was individually analyzed, aiming the screening of publications that in fact referred to the application of the statistical methods of interest in studies on seed germination, reaching a final number of 32 articles for the survival analysis. The search was performed in January 2021.

Bibliometric study

Once the search terms were defined for survival analysis, the bibliometric study was developed on two fronts: one exclusively quantitative and the other qualitative, focusing on the records for the survival analysis in seed germination studies.

For the quantitative analysis, the following variables were considered: relations of publications among areas of knowledge, annual evolution of scientific production, countries, and journals in which the articles were published, and research institutions responsible for the performance of the studies.

From the perspective of the qualitative analysis, each of the 32 articles related to the use of survival analysis was categorized into three groups in view of their general application in studies on seeds, comprising: germination, emergence and/or vigor. Therefore, germination was regarded as the biological concept that corresponds to the protrusion of the radicle to a length greater than 2 mm, and emergence as the identification of seedlings with enough development for species differentiation and/or identification (HEERDT et al., 1996). Regarding the definition adopted for vigor, despite its broad definition, its understanding as a variable for the application of statistical analyses was based on the presence and use of typical seed vigor tests in the analyzed articles, such as accelerated aging test, electrical conductivity, tetrazolium, and cold test.

Furthermore, the publications were also classified regarding the themes and potentialities for the application of survival analysis in seed germination studies, so that each article was categorized into one of the five comprehensive sets, but distinguished from each other, here established, namely: Physiological Studies, Plant Ecology, Seed Dispersion, Weed Management and Methodological Propositions.

From this perspective, the set of Physiological Studies encompasses publications related to the analysis of the germination phenomenon under different abiotic and biotic variables that affect seed performance, such as salinity, moisture, temperature, density, and dormancy. The set Plant Ecology covers articles developed from the perspective of evaluating germination with a component of succession, establishment, and maintenance of ecosystems, as well as feasibility and planning of restoration practices and the effects of anthropic actions and climate changes in the germination process. The group of Seed Dispersion refers to the publications that evaluated the effect of seed dispersion dynamics and strategy on germination and viability. Weed Management integrates the publications that aimed at understanding the behavior of plants considered as weeds in relation to environmental factors. Finally, regarding the set of Methodological Propositions, it encompasses articles that have the main goal of proposing survival analysis methods and tools for studies related to seed germination.

Limitations of the study

Among the main limitations of the present study, we acknowledge that fixing the unique terms "*survival analysis" and "germination"* for sampling might not reflect the totality of the research segment analyzed for the period, since articles relevant to the topic that do not fit the indexing terms might not have been selected. We add that the study was developed using only the Web of Science database, the most traditional and consolidated in bibliometric searches, and it is worth highlighting that no database has full global scientific coverage (FAPESP, 2011).

Additionally, we emphasized that the aim of this study is not directed to the analysis of the experimental quality of the research, a not viable perspective using exclusively bibliometric indicators, but instead, understanding the importance and potential of use and applicability of the survival analysis in seed science.

Results

1. Quantitative overview of the statistical survival analysis in germination studies

The two main research areas encompassed by the publications in the survival analysis were "plant science" and "environmental sciences and ecology", and only 3 articles were included in the field of "agriculture" (Figure 1). The studies involving seed germination are mostly based on ANOVA models followed by means tests for the comparison of treatments (BEZERRA NETO et al., 2002), which explains the low participation of the research field "agriculture" in the publications related to survival analysis.

Furthermore, the designation of several articles on survival analysis included in "plant science" covers publications that studied germination

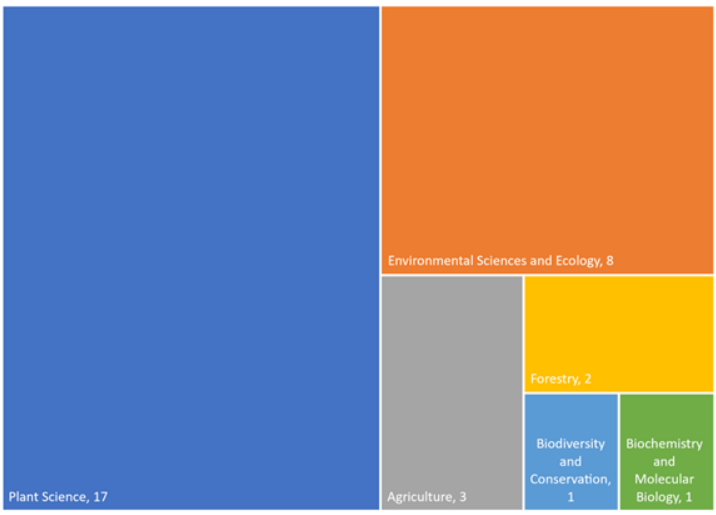

Figure 1 - Number of published articles, per research field, that have used the survival analysis for the interpretation of data on seed germination, in the period from 2000 to 2020. Data Source: Web of Science (2021).

under different focuses, but which converge to the consensus of a comprehensive field. In this regard, it is emphasized that this composition is the result of the category that each journal defines as the focus of their publications, with the researcher being subject to this category by the database chosen as data source, without details on the topic.

There is an inconstancy in the number of published researches, with the date of the first research being in 2000, in which the germination and emergence of *Digitaria californica* (Benth.) Henrard were evaluated under different water contents (SMITH et al., 2000). From 2016, a greater number of publications is observed, but with great variation in the subsequent year and signs of maintenance until 2020, demonstrating that the technique is little applied in seed science (Figure 2).

In addition, despite great inconsistency observed over the years, which, at first, may lead to the interpretation that the statistical method of survival is still applied as a test or validation for seed science, it should be noted that it has been explored since 1982, when SCOTT & JONES (1982) studied the influence of low temperatures on the germination of tomato species (*Lycopersicon* sp.), and the qualitative data evidenced the range of applications and functionalities already studied.

Finally, the countries that most contributed with studies on germination using the survival analysis were: The United States (40.63%), Italy (12.5%), Brazil, China and Poland (6.25%), besides Germany, Austria, Belgium, Canada, Spain and France, with 1 publication each (Figure 3). Concerning the journals in which the publications were performed, there are 26 different journals, with only one of them Brazilian (Ciência Florestal) (Table 1). Among them, 13 are North American journals, which were responsible for half of the analyzed in the period.

In general, the quantitative panorama presented here shows that survival analysis; although, it is an adequate technique for the study of germination data, is still little used in studies on seed science. Thus, it is clear the importance of highlighting the applications and potentialities of survival analysis in works in the area, which will contribute to the gain of information and pertinent interpretations regarding the phenomenon under study.

2. Qualitative analysis: applications and trends of the survival analysis in germination studies

By the survey and categorization of the 32 articles regarding the general application (germination, emergence and/or vigor) and thematic axes defined here for publications in seed science (Table 2), it becomes evident that the survival analysis was predominantly directed to the study of the phenomenon of germination, with lower proportions for the studies on emergence and vigor,

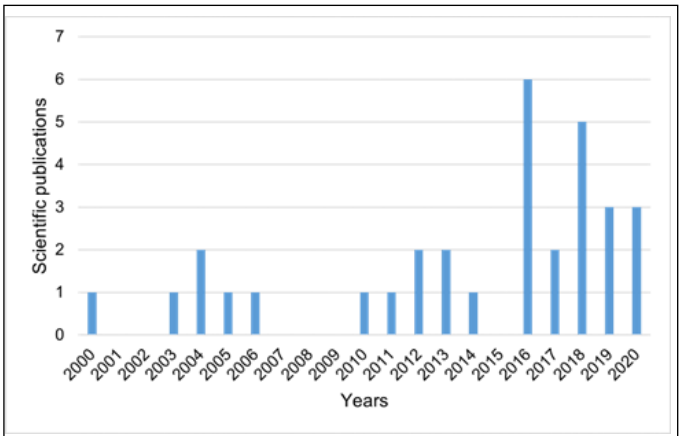

Figure 2 - Absolute frequency of the evolution of the scientific production relative to the application of the survival analysis in seed germination studies, in the period from 2000 to 2020. Data Source: Web of Science (2021).

what is intrinsically associated with the germination data structure (1 in case the seed germinates or 0 in case the seed does not germinate), as well as the fact that the survival analysis allows the allocation of censored data in the estimation of the parameters, being this a characteristic aspect of germination data.

Considering the thematic axis aimed at the physiological studies, the starting point regarding the application of survival analysis techniques in germination studies is consistent with the work performed by SMITH et al. (2000), in which the behavior of predictive germination and; consequently, of the emergence of two populations of *Digitaria californica* (Benth.) Henrard subjected to different water availabilities was evaluated. In this study, the Probit Analysis was applied to understand the necessary amount of an environmental factor to reach a certain response level and the survival analysis as a resource to determine the necessary time to reach 50% of germination/emergence.

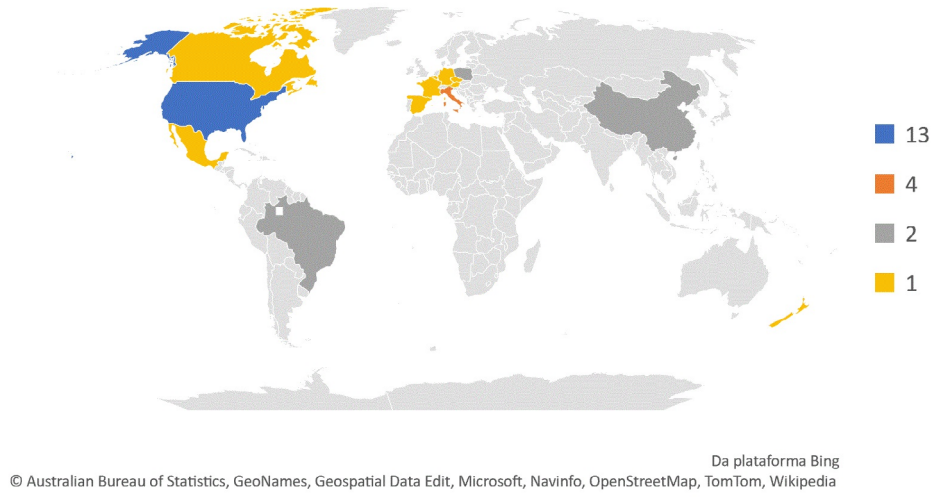

Figure 3 - Representation of the countries participating in the publication of articles that have used survival analysis for data of studies on seed germination, in the period from 2000 to 2020. Data Source: Web of Science (2021).

Table 1 - Main journals that have published articles related to the survival analysis in studies on seed germination, in the period from 2000 to 2020. Data Source: Web of Science (2021).

Journals	Publications	Journal Impact Factor[1]
Seed Science Research	3	1.585
American Journal of Botany	2	3.325
Annals of Botany	2	5.040
Ecology and Evolution	2	3.167
Weed Research	2	2.117
Acta Oecological - International Journal of Ecology	1	1.930
Acta Societatis Botanicorum Poloniae	1	1.123
Applied Vegetation Science	1	3.431
Austral Ecology	1	1.771
Castanea	1	0.255
Ciência Florestal	1	0.630
Dendrobiology	1	0.972
Environmental Pollution	1	9.988
Evolutionary Ecology Research	1	1.094
Hort Science	1	1.874
Journal of Ecology	1	6.381
Journal of Tropical Ecology	1	1.800
Forest Ecology and Management	1	4.384
Oecologia	1	3.298
Plant Growth Regulation	1	3.242
Plant Methods	1	5.827
Forest Science	1	1.742
Plant Biosystems	1	1.781
Plant Ecology	1	1.990
Plants-Basel	1	4.658
Tropical Conservation Science	1	1.721

[1]Data Source Impact Factor: Journal Citation Reports™ 2021.

In a study directed to the tolerance of *Iris hexagona* Walter seedlings to salinity (VAN ZANDT & MOPPER, 2004), the survival analysis was applied to compare differences in the germination time of seedlings subjected to treatments under three variables: saline index, maternal populations, and pollen donors. Therefore, among other aspects, a greater success of *I. hexagona* germination was determined, in other words, higher indexes per time, for seeds derived from maternal plants produced in environments of high salinity, which refers to the knowledge of a fundamental adaptive capacity for plants usually subjected to this type of environmental stress.

Such is relevant information for the understanding of the physiological behavior of the species regarding its reproductive strategies, obtained precisely by the survival analysis. Therefore, the possibility of correlating the survival analysis with other variables relevant to the germination phenomenon is evident, based on the development of statistical models.

Years later, ADEGBOLA & PÉREZ (2016) applied the survival analysis to the evaluation of desiccation and tolerance to aging stresses in seeds of *Gaillardia pulchella* Foug, with the aim of obtaining perspectives on the germplasm storage potential and vigor of the species. The authors analyzed the data obtained by accelerated aging tests with salt-saturated atmosphere by the method of the Kaplan-Meier product-limit and compared the treatments by the log-rank statistics. Furthermore, for the evaluation of the germination time patterns, Cox proportional hazards models were developed. Under a similar focus, GENNA & PÉREZ (2016), investigating the germination of three classes of *Rudbeckia mollis* Elliott seed mass, adopted the same survival analysis techniques to evaluate the germination time standards by the simulation of seasonal temperatures, supra-

Table 2 - Categorization of articles that have used survival analysis for seed germination data, in the period from 2000 a 2020.

Categories	Scientific Publications				
	Physiological Studies	Plant Ecology	Methodological Propositions	Seed Dispersal	Weeb Management
Germination	SMITH et al. (2000) VAN ZANDT and MOPPER (2004) GENNA and PÉREZ (2016) PÉREZ and KANE (2017) MESSICK and HOAGLAND (2018) SZYMAJDA et al. (2019)	WINKLER et al. (2005) AERTS et al. (2006) SOLARIK et al. (2016) CONNOLLY et al. (2017) BARAK et al. (2018) OLIVEIRA et al. (2019)	ONOFRI et al. (2010) ONOFRI et al. (2011) MANSO et al. (2013) ROMANO and STEVANATO (2020)	TANG et al. (2012) HARICH et al. (2016) O-FLORES et al. (2018)	DÉLYE et al. (2013) CRISTAUDO et al. (2014)
Emergence	SMITH et al. (2000) VAN ZANDT and MOPPER (2004) SZYMAJDA et al. (2019)	FORBIS (2003) FORBIS et al. (2004) WINKLER et al. (2005) AERTS et al. (2006)	ONOFRI et al. (2010) ONOFRI et al. (2011) HUMPLÍK et al. (2020)		DÉLYE et al. (2013)
Vigor	ADEGBOLA and PÉREZ (2016) GENNA and PÉREZ (2016) PÉREZ and KANE (2017)				

optimum temperatures, and aging stresses by saline saturation; and PÉREZ & KANE (2017) evaluated the response of germination in two populations of *Uniolapaniculata* L. subjected to desiccation and cryopreservation treatments.

In these studies, the allocation of censored data in the analyses is made explicit, being this a particularly important aspect considering the conditions of salinity and low temperatures involved, which correspond to scenarios adverse to germination, delaying or rendering unfeasible a certain number of seeds.

Therefore, concerning the studies involving seed dormancy, MESSICK & HOAGLAND (2018) evaluated different cold scarification treatments (no scarification, 30 days, and 60 days) and soil types (native soil and in greenhouse) in relation to the production of seeds and the physiological needs for *Penstemon oklahomensis* Pennell germination, using the survival analysis (Kaplan-Meier estimator and Cox proportional hazards model) to estimate the probability of seed germination for each treatment. SZYMAJDA et al. (2019) developed experimental assays based on the statistical methodology of survival analysis (Cox proportional hazards model, Kaplan-Meier estimates and Peto-Peto test) to evaluate the effect of different pretreatments of seeds in three cultivars of peach (*Prunus persica* (L.) Batsch) and three cultivars of apricot (*Prunus armeniaca* L.). The results of treatments demonstrated optimization of the germination process over time, enabling the acquisition of a higher number of seedlings, which can help in the programs of genetic improvement of these species.

On the thematic axis related to plant ecology, in studies with perennial plant communities from alpine habitats (FORBIS, 2003; FORBIS et al., 2004), the application of survival analysis models linked to climate variables to determine survival rates of newly emerged plant organisms enabled the understanding of the behavior of different plant communities regarding the characteristic seasonality of these ecosystems and this influence on seedling mortality for each season. Thus, even not being the primary goals of the referred works, since they are aimed at ecological evaluation, it becomes evident that the application of the survival analysis

enables accurate determinations concerning aspects indispensable to plant development, as the example of the sensitivity of the process of development and establishment of plants to factors such as moisture, temperature, and environmental disturbances in the habitat of the species.

WINKLER et al. (2005) used the survival analysis to study features of forest substrates and of the exposure to luminosity in the germination and survival of epiphytic bromeliads in a mesophilic forest, aiming at understanding the most appropriate scenarios for the germination of the studied species and the factors which influence population size and the growth rates of this group of plants. From an analogous perspective, AERTS et al. (2006) performed a study to evaluate the germination, establishment, and survival of olive seedlings (*Olea europaea* L.) exposed to different microhabitats provided by pioneer shrub species, to evaluate whether the recruitment and survival of seedlings is dependent on these microhabitats, where the survival analysis was employed for the treatment of the data.

In this context, the authors used the survival analysis (Kaplan-Meier estimator, Breslow test statistics and Cox proportional hazards model) as a tool to evaluate the differences in the dynamics of species reproduction given the factors that generate environmental instability, being an opportune method for such analysis, since time is characterized as a response variable in population stability these organisms.

Regarding environmental factors, SOLARIK et al. (2016), in order to assess the impact of local adaptation, temperature and the influence of the change in temperature on *Acer saccharum* Marshall (sugar maple) seed germination, demonstrated that the experimental procedure based on the estimation of germination by the Kaplan-Meier method, besides being appropriate to quantify the variable germination in face of several influencing factors (incubation temperatures, increase in temperature and decrease in the temperature of germination), was able to consistently evaluate the potential impacts of climate warming on the reproductive success of the species.

Considering forest ecology, climate change and anthropic management, CONNOLLY et al. (2017) developed tests to examine the effect of the application of a contact fungicide and of five cold stratification treatments on the germination of five shrub species of great occurrence in temperate forests in the northern hemisphere (*Abies balsamea* (L.) Mill., *Acer saccharum* Marshall, *Picea glauca* (Moench) Voss, *Pinus resinosa* Aiton and *Pinus strobus* L.). In this study, applying the survival analysis by Cox proportional hazards models, it was concluded, among other points, that the germination rate of seeds from certain species may be affected by the action of the fungicide in specific periods of stratification, reinforcing the importance of analyzing these effects on long-term scales on the vigor of seedlings obtained in conservation and restoration projects.

Regarding conservation and restoration ecology, BARAK et al. (2018) analyzed, by the adequacy of a Cox proportional hazards model, the degree in which the characteristics of the seed (mass, shape and embryo: seed ratio), phylogenetic aspects and pre treatments for dormancy (cold stratification, gibberellic acid and control) are predictive in the germination time of 32 species commonly used in the restoration of pastures in the Midwest USA, resulting in important conclusions for understanding the assembly of communities through ecological restoration. OLIVEIRA et al. (2019) used the survival analysis (Kaplan-Meier estimator and log-rank test) to evaluate the tolerance of germination of 9 shrub species typical of the Brazilian Pantanal and Cerrado employing different flood treatments, to understand if this feature is related to species distribution by the flood gradient typical of the biome Pantanal and its relation in the dynamics of the regeneration niche.

Therefore, these studies evidence that a better understanding of factors that are predictive for germination, emergence and establishment of plants characterizes an aspect of fundamental ecological importance for the guidance and effectiveness of practices and research aiming the understanding, planning, conservation, and restoration of ecosystems, and they can be investigated by survival analysis, since these phenomena are associated with time.

Addressing the topic of methodological propositions, ONOFRI et al. (2010) developed the proposition of the survival analysis as the method for evaluation of data on germination and emergence for weed species, this being a theoretical reference of great importance for the application of the survival analysis in studies on seed germination. In this study, the authors demonstrated through the analysis of experimental data the flexibility and adequacy of the survival analysis for the data on germination in comparison with the use of ANOVA, since these data are not normally distributed, they may imply in the autocorrelation of errors, and they typically present censorship.

In this continuity, MANSO et al. (2013) proposed a proportional hazards model for seed germination of forest tree species under natural

conditions, correlating thermal variables, variables of water availability, and of dissemination/ population of individuals. It is worth highlighting that the authors emphasized the evaluation of the germination process by the proposed model without the need for strong assumptions on time distribution until the event, being this an important aspect in terms of comprehensiveness of the model given the observation of high precision and no apparent bias in relation to the analysis of data on germination.

In an article developed under the focus of the proposition of the Bayesian approach for the survival analysis in a computational method, HUMPLÍK et al. (2020) developed tests, exclusively to obtain data, with different treatments of saline stress and stimulating compounds on the emergence of corn (*Zea mays* L.) seedlings, by which high solidity and reliability of the proposed method were verified for the analysis of the data until the time the event of interest occurred. Furthermore, it is highlighted that the method proposed by HUMPLÍK et al. (2020) presents broad applicability for several variables pertinent to research on seeds, such as germination, emergence, appearance of the first leaf, flowering, fruit ripening etc., being able to evaluate the intrinsic uncertainty of the data on the time until the event.

Finally, ROMANO & STEVANATO (2020) evaluated the application of three approaches of the survival analysis (Kaplan-Meier estimator, Cox proportional hazards models and accelerated failure time model) in germination data of seeds of different *Beta vulgaris* L. genotypes subjected to osmotic stress, to contribute to the knowledge of the reliability of these methods. In this sense, the results led to the conclusion that among the advantages and disadvantages typical of each approach, Cox proportional risk model is consistent when considering a set of covariates that influence germination simultaneously; and the accelerated failure time model is adequate in terms of the speed of processes that end with the germination event, when the objective is to evaluate germination in response to environmental factors (herbicide effect, precocity of varieties, for example).

Another segment of interesting application of the survival analysis observed in the scientific publications involving studies on germination concerns the dynamics and strategies of the dispersion of seeds of plant species.

In this sense, studying the influence of the dispersion promoted by fruit bats on the germination of *Syzygium oblatum* (Roxb.) seeds, TANG et al. (2012) used the survival analysis as a statistical method to compare three germination habitats where the seeds of the studied species can be directed by the zoochoric dispersion promoted by these mammals. Aiming to determine seed viability at the different locations, the probabilities of germination were obtained by the Kaplan-Meier estimator, and the comparison of the treatments was performed by the log-rank test.

In this logic, studying seed dispersion by animals, HARICH et al. (2016) employed survival analysis techniques (Kaplan-Meier estimator, log-rank test, Wilconox, Tarone-Ware, Peto and Fleming-Harrington) in the evaluation of the germination rate of *Dillenia indica* L. seeds ingested by Asian elephants (*Elephas maximus*), as a means of understanding the importance of frugivory of large herbivores in the regeneration and perpetuation of plant species.

Moreover, ORTEGA-FLORES et al. (2018) applied the survival analysis (Kaplan-Meier estimator and log-rank test) in germination assays with *Schinus terebinthifolius* Raddi, aimed to evaluate the potential effect of the zoochoric dispersion performed by the fruit-eating bird *Turdus rufopalliatus*. Therefore, the authors performed germination tests with seeds from four different treatments, in which, although not observing statistical differences in the probabilities of germination, they observed the existence of a pattern of lower probability of germination over time in intact seeds, an association which may become a problem for the preservation of the native biodiversity in countries in which this species is considered an invasive species.

Thereby, the survival analysis applied as a statistical method in these studies demonstrated the influence of seed dispersion by biotic agents on germination over time, an aspect that from a long-term perspective influences the stability of plant species in the environment, both in desirable routes and in the case of preservation, as undesirable regarding invasive species.

Finally, for weed management, working with induced resistance in weeds, DÉLYE et al. (2013) used survival analysis methods (Kaplan-Meier estimator and accelerated failure time regression model – AFT) to evaluate the pleiotropic effects of three mutant alleles (Leu1781, Gly2078 and ASN 2041) that give the plants resistance to ACCase-inhibiting herbicides in the survival of seeds in the soil. Thus, seedling germination and emergence were evaluated in populations of *Alopecurus myosuroides* Huds. regarding the effects of each mutant allele.

In this scenario, it is worth highlighting that the methodologic approach adopted by DÉLYE et al.

(2013) derives from the proposition of ONOFRI et al. (2010), being important to emphasize, in the field of weed sciences, that the germination data worked by the survival analysis enabled the demonstration of direct effects of herbicide resistance on important characteristics for the dynamics of development of *A. myosuroides* in the production environment, an aspect which, generalized for the study of weeds, is characterized as fundamental for the ideal agricultural management.

Considering more elaborated analyses, CRISTAUDO et al. (2014) applied the parametric survival analysis of "Cure model", proposed by ONOFRI et al. (2011), to assess the germinative response of *Amaranthus retroflexus* L. to two environmental factors, namely temperature and luminosity. In this context, the good description and adjustment of the data achieved by the model is denoted, in which the authors emphasize that the possibility of prediction of germination and emergence related to environmental conditions is an important biological tool for assistance in decision making in the aspects of weed management.

For the researches encompassed in the thematic axes, it is important to highlight that the employment of the survival analysis occurs mainly by the application of models and adequacies that allow the correlation of the time response variable with the other variables under study, in other words, they are researches that are mostly developed under a combination of non-parametric and parametric approaches of the survival analysis. Thus, the frequent use of the Kaplan-Meier estimator to estimate the survival function is observed, as well as the application of tests for the comparison of curves corresponding to different groups, as the example of the log-rank test, highlighting the importance of this estimator as a very useful resource in the individualized evaluation of the factors of influence on failure time, in other words, the time until the event of interest occurs. Nevertheless, when the researches aim to evaluate multiple factors together, they use more sophisticated survival techniques, such as the Cox proportional hazards models, for instance.

CONCLUSION

In summary, the quantitative overview presented here demonstrated that the survival analysis is a statistical method little used in studies with seeds, with the USA being the country with the highest number of publications, mainly to studies in plant ecology and physiology. However, the qualitative overview demonstrated that the survival analysis is a statistical tool of great potential regarding the studies in the area. In general, the researches were most involved to the evaluation of factors influencing dormancy, physiological stresses, dispersion capacity, population differences and habitats of development which affected seed germination. So, even its use in articles being low for the period analyzed, its applications and adaptations to several variables of interest for the germination, emergence and/or vigor process highlight this statistic method as an option to be considered for the treatment of germination data.

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DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTIONS

All authors contributed equally for the conception and writing of the manuscript. All authors critically revised the manuscript and approved of the final version.

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