Correlation between Relative Humidity and Forest Seeds Moisture on the Incidence of Fungi

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The objective of the research was to evaluate the effect of relative humidity (RH) and moisture content (MC) on the incidence of pathogenic fungi on the seeds of Agave lechuguilla, Lippia graveolens, and Nolina cespitifera. Seeds were stored 90 days at 60, 75, 80, and 85% RH, and results were processed with a correlation analysis in the R software using the Spearman test. Higher fungi incidence (FI) in seeds was found from 10 to 20% RH; however, correlation between RH and MC of seeds was positive with \( r = 0.311 \) and \( p = 2 \times 10^{-16} \). In general, RH is related to MC, but not to fungi incidence, which is related mainly to MC of seeds. Correlation between RH and FI for each seed species was not significant, \( r = 0.026, -0.040, \) and \( 0.071 \) and \( p = 0.687, 0.540, \) and \( 0.272 \) for \( A. \) lechuguilla, \( N. \) cespitifera, and \( L. \) graveolens, respectively. There was a positive correlation between the MC of seeds with fungi incidence; a negative correlation between the RH and the FI; and a positive correlation between the RH and the MC of seeds. In this type of seeds (orthodox), the MC is probably the most important factor in determining its longevity. The seeds under study can be stored in a 60% to 75% RH. Five fungi genera were found, predominating Aspergillus with five identified species.

1. Introduction

The seed bank (SB) is an ex situ conservation technique used to expand their viability [1] with the aim of supporting the species survival in nature [2] as well as for research and their propagation [3]. Seed storage (SS) is essential for the preservation of physical, physiological, and sanitary qualities, ensuring conservation of genetic diversity of many species for scientific research and agriculture [4]; however, maintaining their viability depends on storage conditions [5].

The period in which seeds remain viable is genetically determined by internal as well as by environmental factors [6, 7], such as environmental conditions during production, pests, diseases, oil content, MC (variable), mechanical damage during processing, storage time, packaging materials, pesticides, air temperature, and RH (variable), as biochemical damage of seed tissue [8–13]. In relation to storage conditions, the MC in seeds and high temperatures are possibly the most important factors which influence seed quality (QS), such as viability and vigor [14–19]; however, the most critical factor is MC [20–22] since small changes in the MC have a great effect on the storage life of seeds [23], that is, seeds stored with low MC or low RH retain their viability for a longer period [24]; however, typical orthodox seeds age and gradually lose their viability when stored [25].
Seed storage can be a challenge, given their inherent nature; however, orthodox seeds can survive desiccation at 3 to 7% MC and temperatures as low as −20°C for indefinite storage period at less than 60% humidity [26–30]. Various mechanisms have been proposed to explain this cytoplasmic resistance to dehydration [31, 32]; one seems to be the role played by water bound to macromolecules, whose presence and disposition prevents irreversible alteration. In orthodox seeds, to increase longevity and limit their deterioration, the MC and storage temperature is reduced [18, 33, 34], and specifically, the long-term conservation of orthodox seeds is generally carried out at low temperature and low RH [35], that is, increase in RH and temperature leads to a progressive decrease in the vigor due the deterioration caused by the loss of the integrity of the membranes [36] and for conservation of the physiological quality (viability, germination and vigor) of seeds for long periods of time. It is necessary to know the physiological behavior (recalcitrant, intermediate or orthodox) of seeds in storage [37].

Experiments have shown that there are thresholds for the beneficial effects of drying, where below a critical level of seeds MC will not improve longevity [38] and may even have a detrimental effect on survival during processing and storage [39, 40]. Reducing MC to certain thresholds increases longevity in a predictable way in approximately 90% of species [41], that is, favorable conditions and inadequate storage systems [42–44] such as high temperature and humidity can not only can affect yield and seed quality but also reduce vigor and SS capacity [45–48], loss of viability [49], and seed deterioration during storage characterized by a progressive loss of viability, vigor, and even death [50] causing considerable losses [42].

Furthermore, storage under inappropriate conditions can lead to microorganism development, loss of dry matter, heating, increased humidity, high levels of free fatty acids in the extracted oil, and low of seed germination [51]; high RH and temperature can favor fungi and insects activity, thus reducing SQ [52]. On the other hand, iyoti [53] mentioned that seeds stored at high MC show an increase in respiration, warming, and fungi invasion. Fungi infected seeds can survive for 5 years if air is dry and stored at 4°C [54], playing an important role in seed degradation during poor storage, being unsuitable for planting and consumption not only for humans but also for domestic animals [55, 56]. Seed-borne pathogens can be the main source of infection and disease transmission [57], for instance: Alternaria Nees (Pleosporaceae), Aspergillus P. Micheli ex Haller, (Trichocomaceae), Botrytis P. Micheli ex Haller (Sclerotiniaceae), Cladosporium Link ex Fr. (Cladosporiaceae), Curvularia Boedijn (Pleosporaceae), Doratomyces (Corda) (Microascales), Fusarium Link (Nectriaceae), Helminthosporium Link (Massarinaceae), Macrophomina Petrúck (Botryosphaeriaceae), Nigrospora Zimm (Trichosphaeriaceae), Penicillium Link (Trichocomaceae), Chaetomium Kunze (Chaetomiaceae), Pestalotia De Not. (Aspergillariaceae), and Rhizopus Ehrenb. (Rhizopodaceae) represent the most associated fungi with seeds under storage conditions [58, 59].

The most important nontimber forest products from arid and semiarid climates are as follows: lechuguilla, candelilla, oregano, sotol, yucca, agave, jojoba, gobernadora, and cortadillo [60], with social, cultural, or economic importance; in Mexico, there are 42 species of Agave to produce mezcal [61], and approximately 26 states of Mexico grow agave [62, 63]; in that matter, knowledge of SS is essential to plan strategies for conservation of plant genetic resources [64]. Due to the lack of necessary information to provide optimal seed storage conditions for orthodox species from arid zones, the objective of the research was to evaluate the effect of RH and MC in seeds of A. lechuguilla, L. graveolens, and N. cespitifera and their relation with pathogenic fungi incidence.

2. Materials and Methods

2.1. Experiment Location. Research was carried out at Centro de Capacitación y Desarrollo de Tecnología de Semillas (CCDTS) of Universidad Autónoma Agraria Antonio Narro, in Saltillo, Coahuila. Lechuguilla seeds Agave lechuguilla Torr. (Asparagaceae), oregano Lippia graveolens Kunth. (Verbenaceae), and cortadillo Nolina cespitifera Trel. (Asparagaceae) were used (Figure 1), obtained from seed lots of natural populations, from southeast Coahuila, collected in 2016 (Figure 2).

2.2. Time and Storage Conditions. Seeds of A. lechuguilla, N. cespitifera, and L. graveolens were stored for a 90-day period at 60, 75, 80, and 85% RH. To reach 60% RH under storage conditions, a saturated glucose solution (C6H12O6) was used. For 75% RH, a chloride solution (NaCl) was used, whereas for 80% and 85%, solutions of ammonium sulfate (NH4)2SO4 and potassium chloride (KCl) were used, respectively [65]. A total of 36 treatments were performed (3 types of seeds; 4 RH percentages, and 3 seed MC) with 20 replicates and 100 seeds per each one. Seeds were placed in a perforated cloth sealed with adhesive tape so that solutions could acted correctly and samples were evaluated during 90 days. Initial evaluation was carried out before storage in order to know the MC of the seeds and the physiological stage, and seeds were later subjected to humidity test in aluminum containers in a drying oven at a temperature of 103°C for 17 h based on the International Seed Testing Association [66]. The MC of seeds was determined with the following formula: MC (%) = fresh weight – dry weight/dry weight × 100. Pathogens were isolated in ADP culture medium and identified by morphological criteria.

2.3. Analysis of Results. Results were expressed in percentage and processed in a correlation analysis in R software by means of Spearman test [67].

3. Results

The RH environments evaluated in the three types of seeds (A. lechuguilla, L. graveolens and N. cespitifera) were from 60 to 85%; in the MC, a numerical variable was obtained, but with continuous values, which ranged from 2.06 to 24.07%. In the correlation between RH and FI in the different seeds,
with a correlation coefficient \( r = 0.0205 \) and \( p = 0.5835 \), the correlation was not significant (Figure 3(a)), whereas in the MC of the seeds and the FI with \( r = 0.2678 \) and \( p = 2.717 \times 10^{-13} \), the correlation was positive and significant, that is, both variables increase or decrease together, while in the relation of the MC of the seeds and FI, it indicates that, as one variable increases, the other can decrease or increase (Figure 3(b)).

In the correlation between RH and seed MC, a perfect straight line with a positive slope is observed; that is, a positive correlation was obtained with \( r = 0.311 \) and \( p = 2.2 \times 10^{-16} \) (Figure 3(c)), in which the RH is related to MC, but not to FI, which is related to seeds’ MC (Figure 4).

Figure 5(a) shows that \textit{N. cespitifera} seeds tend to have higher FI when compared to \textit{A. lechuguilla} seeds and especially with \textit{L. graveolens} seeds. Correlation between RH and FI for each seed species was not significant (Figure 5(a)), with values of \( r = 0.026 \), \(-0.040 \), and \( 0.071 \) and \( p = 0.687 \), \( 0.540 \), and \( 0.272 \) in \textit{A. lechuguilla}, \textit{N. cespitifera}, and \textit{L. graveolens}, respectively. In the correlation of FI and MC, the \( r = -0.029 \), \(-0.039 \), and \( 0.110 \) and \( p = 0.6520 \), \( 0.5520 \), and \( 0.0861 \) were not significant (Figure 5), showing the highest percentages of MC in the \textit{A. lechuguilla} seeds (Figure 6), and the RH correlation with seeds MC was positive (Figure 5(c)), with values of \( r = 0.53 \), 0.68, and 0.37 and \( p = 2.02^{-18} \), \( 1.52^{-33} \), and \( 3.81^{-09} \) in \textit{A. lechuguilla}, \textit{N. cespitifera}, and \textit{L. graveolens}, respectively.

\textit{Fusarium} sp. and \textit{Alternaria} sp. were observed at 60% RH with values in seeds’ MC of 9.11 to 9.15% in \textit{A. lechuguilla} and \textit{N. cespitifera}. In addition to \textit{Fusarium} sp. and \textit{Alternaria} sp., \textit{Cladosporium} sp. and \textit{Aspergillus versicolor} (Vuill.) T. (\textit{Aspergillaceae}) were observed from 4.76 to 12.41% MC, whereas in \textit{L. graveolens}, no pathogens were found. In the range of 60–74% RH, no pathogens were found in seeds. At 75% RH, the same pathogens began to appear in \textit{A. lechuguilla} and \textit{N. cespitifera}, but not in \textit{L. graveolens}; at 80% RH, also \textit{A. glaucus} and \textit{A. niger} appeared in \textit{A. lechuguilla}; in \textit{N. cespitifera}, \textit{A. glaucus}, \textit{A. ochraceus}, and \textit{Penicillium} sp. also appeared, and for the first time in \textit{L. graveolens}, \textit{A. glaucus}, \textit{A. niger}, and \textit{Penicillium} sp. were found. Finally, at 85% RH in \textit{A. lechuguilla}, \textit{Cladosporium} sp., \textit{A. terreus}, and \textit{A. glaucus} were detected; in \textit{N. cespitifera}, the same pathogens remained, and in \textit{L. graveolens}, \textit{Penicillium} sp., \textit{A. ochraceus}, and \textit{A. ochraceus}. It should be noted that \textit{A. glaucus} and \textit{Alternaria} sp. were the pathogens with the highest incidence, with over 75% in the seeds (Figure 7).

4. Discussion

Currently, three main categories of the physiological behavior of seeds in storage are recognized: orthodox, intermediate, and recalcitrant [1, 68], and their storage depends on each type [69, 70]; the seeds under this study: \textit{A. lechuguilla}, \textit{L. graveolens}, and \textit{N. cespitifera} are orthodox,
Figure 3: General correlations between variables under study. (a) Correlation of HI and RH; (b) correlation of HI and CH of the seeds; (c) correlation of CH of the seeds and RH.

Figure 4: RH, MC, and FI correlation matrix. Pearson’s correlation coefficient and the significant level indicated by an asterisk are shown in the upper triangular matrix. Significant levels are represented by **. Histograms and scatterplots for RH, MC, and FI are shown in the lower diagonal and triangular matrix, respectively.
and the main characteristic of this type of seeds is that they
dried at low MC [71] and conserved without any incon-
venience for long time [72]; however, deterioration of the
storage seeds depends on the conditions in which it is done,
that is, deterioration of the seeds could affect vital functions
causing their death [73].

Long-term conservation in SB is based on increasing
longevity of the stored seeds, which depends on size, MC,
chemical composition, and storage conditions such as
temperature, RH, or the type of packaging used (plastic,
glass, aluminum, and paper) [74, 75]. Ex situ conservation
has been the main approach to preserve genetic diversity
associated with cultivated plant genetic resources worldwide
because it is more likely to be investigated, characterized,
and used than if they are conserved in situ [76], understand-
ing that seeds will remain viable from the beginning to
the end of storage, being alive and able to germinate when
removed from storage [77]. In orthodox seeds, longevity
increases with the reduction of MC and storage temperature
[34], being tolerant to desiccation, they disperse and con-
serve after reaching a low humidity percentage [78] and can
be stored years to decades or centuries, depending on the
species [18]. In addition, ex situ conservation is a priority
activity of the global plan of action to achieve conservation
and sustainable use of plant resources of interest for food
and agriculture [79].

In addition to the importance of A. lechuguilla, L. graveolens,
and N. cespitifera, some endangered species have priority within the phylogenetic resources for their in vitro
conservation, and Agave is one of them as well as Allium L. (Amaryllidaceae), Ananas Mill. (Bromeliaceae),
Canna L. (Cannaceae), Colocasia O. (Araceae), Ficus

Figure 5: Correlation of the variables and seed types under study. (a) Correlation of FI and RH; (b) correlation of FI and seed MC;
(c) correlation of seeds MC and RH; AL = A. lechuguilla, LG = L. graveolens, and NC = N. cespitifera.
L. (Moraceae), *Ipomea* L. (Convolvulaceae), *Musa* L. (Musaceae), *Olea* L. (Oleaceae), *Piper* L. (Piperaceae), *Saccharum* L. (Poaceae), *Solanum* L. (Solanaceae), *Vanilla Plumer ex Miller* (Orchidaceae), *Vitis* L. (Vitaceae), *Xanthosoma Schott* (Araceae), and tubers such as fruit trees among others [80–82]. The importance of seeds under study is big; for instance, *A. lechuguilla* is used for the production of aguamiel and pulque, as distilled alcoholic beverages such as tequila and mezcal, and also to obtain fibers, food, and materials for ornaments and construction, among others [83]; *N. cespitifera* is important for a large number of families in rural areas of arid and semiarid zones of northeastern Mexico [84]. It is the main source of economic income, obtaining a high resistance hard fiber used as raw material in the manufacture of brooms, brushes, rustic furniture, and explosive cartridges [85], and *L. graveolens* have industrial and pharmaceutical uses; its essential oil is used as a fragrance in soaps, perfumes, cosmetics, and flavorings, [86]; in addition, it is used as a condiment in the
preparation of regional dishes such as sauces, stews, broths, and salads and in international foods as pizzas and the production of sausages [87].

The low disease incidence of *L. graveolens* seeds is probably due to *L. graveolens* has antibacterial, antifungi, antiparasitic, antimicrobial, and antioxidant properties [88], and it has been found that the essential oils of species of the genus *Origanum* L. (Lamiaceae) also have antifungal capacity against *Candida albicans* (Robin) Berkhourt (Debaryomycesaceae), *C. tropicalis* (Castellani) Berkhourt (Debaryomycesaceae), *Torulopsis glabrata* (Anderson) Meyer & Yarrow (Saccharomycesaceae), *Aspergillus Niger* Tieghem (Aspergillaceae), *Geotrichum Link* (Dipodascaceae), and *Rhodotorula* H. (Sporidiobolaceae) but not against *Pseudomonas aeruginosa* (J. Schröter) Migula (Pseudomonadaceae) [89].

Factors such as time and temperature can influence germination, being optimal conditions low temperatures and low humidity content, probably because it reduces the probability of fungi and insect appearance [90, 91], so, the knowledge of MC of seeds under environmental conditions allows the establishment of safe storage times during a given period. Abdul-Bak and Anderson [92] mentioned that when favorable interactions occur between the genetic component and the environment in which the seed is produced, harvested, processed, and stored, the higher quality level is reached. Bonner et al. [93] on the other hand mentioned that it is better to store orthodox seeds with an MC from 5 to 8% since seeds with less than 5% can have problems due to desiccation, and above 9%, there will be problems with insects and fungi; this type of seeds tolerate dehydration of up to 5% [94], whereas 70% RH is needed for optimal development of insects [95].

Other authors state that storage of seeds below 5% of MC increases seed longevity [95]; Copeland and McDonald [96] mentioned that maximum seed longevity is reached with 5 to 6% RH. Seeds MC in which the highest FI was obtained was from 10 to 20%, and at a MC of 5%, a 100% FI was shown for the first time. Importance of MC in the preservation of seeds lies in the role of water in the physiological processes that determine vigor and longevity of seeds, as well as in the development of insects and fungi during storage [97–99].

The activity of field fungi is delayed during storage with a low MC since they require ≥90% RH in the environment for their growth [100], similar to results found in this research, in which the highest incidences of pathogens in the three seed types were at high RH (85%). Results show that fungi began to appear at 65% RH and at 74%, and no pathogen growth was found in none of the seeds. The importance of having seeds without fungal growth in storage (clean and safe) is because contamination of seeds by these pathogens [101] is the most important factors during storage reducing QS causing a negative effect in appearance and chemical composition. In addition, they can also inhibit germination, disease transmission from seed to seedling, reduce crop yield, and threaten food safety [102, 103].

5. Conclusions

There is a positive correlation between MC of seed species and FI, as well as a negative correlation between RH and FI, with a positive correlation between the RH and seed MC.

In these types of seeds, MC is probably the most important factor determining their longevity.

The seeds under study can be stored in a 60% to 75% RH.

Five fungi genera were found, predominating *Aspergillus* sp. with five identified species.

Data Availability

Data are available on request from the authors. All the data are incorporated in the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest.

Authors’ Contributions

Adriana Antonio-Bautista conducted samplings and experiments. Mario Ernesto Vázquez-Badillo designed the research and methodology and conducted samplings and experiments. Armando Rodríguez-García conducted samplings and experiments. Luis Alberto Aguirre-Uribé reviewed and edited the final version of the manuscript. Agustin Hernández-Juárez revised the original draft and prepared the final manuscript. Epifanio Castro-Del Ángel analyzed data. Juan Mayo-Hernández revised the original draft. Jose Luis Arispe-Vazquez analyzed data and revised the original draft and prepared the final manuscript. All authors have read and agreed to the published version of the manuscript.

References

[1] T. D. Hong and R. H. Ellis, “Interspecific variation in seed storage behaviour within two genera: coffee and citrus,” *Seed Science & Technology*, vol. 23, pp. 165–181, 1995.

[2] J. A. Cochrane, A. D. Crawford, and L. T. Monks, “The significance of ex situ seed conservation to reintroduction of threatened plants,” *Australian Journal of Botany*, vol. 55, no. 3, pp. 356–361, 2007.

[3] P. León-Lobos, M. Way, P. D. Aranda, and M. Lima-Junior, “The role of ex situ seed banks in the conservation of plant diversity and in ecological restoration in Latin America,” *Plant Ecology & Diversity*, vol. 5, no. 2, pp. 245–258, 2012.

[4] A. Medeiros and M. T. Eira, *Comportamento Fisiológico, Secagem e Armazenamento de Sementes Florestais Nativas*. *Circular Técnica 126*, Embrapa Florestas, Colombia, Brazil, 2006.

[5] J. Doria, “Generalidades sobre las semillas: su producción, conservación y almacenamiento,” *Cultivos Tropicales*, vol. 31, pp. 74–85, 2010.

[6] L. O. Copeland and M. B. McDonald, *Principles of Seed Science and Technology*, Chapman Hall, New York, NY, USA, 1999.

[7] A. M. Mayer and A. Poljakoff-Mayber, *The Germination of Seeds*, Pergamon Press plc, Headington Hill Hall, Oxford OX3 OBW, UK, 1989.
[8] S. A. Al-Yahya, "Effect of storage conditions on germination in wheat," *Journal of Agronomy and Crop Science*, vol. 186, no. 4, pp. 273–279, 2001.

[9] M. Anfinrud, "Planting hybrid seed production and seed quality evaluation," in *Sunflower Technology and Production*, A. H. Schneiter, Ed., Agronomy, Madison, WI, USA, 1997.

[10] V. Guberac, S. Marić, A. Lalić, G. Drežner, and Z. Đudan, "Hermetically sealed storage of cereal seeds and its influence on vigour and germination," *Journal of Agronomy and Crop Science*, vol. 189, no. 1, pp. 34–56, 2003.

[11] L. G. Heatherly and R. W. Elmore, "Managing inputs for *O. amendoim*: *Tecnologiade Produção* of seeds stored in a genebank: species characteristics," *Comptes Rendus Biologies*.

[12] C. Walters, L. M. Wheeler, and J. M. Grotenhuis, "Longevity and maintenance of high germination ability of dry seeds," *Seed Science Research*, vol. 15, pp. 1–20, 2005.

[13] L. Rajjou and I. Debeaujon, "Seed longevity: survival and the longevity of seeds of *Phaseolus vulgaris*," *Annual Review of Plant Biology*, vol. 1, pp. 671–700, 1973.

[14] J. E. Guevara-Ohara, C. I. Cardozo-Conde, and L. G. Santos-Meléndez, "Tolerance to the desiccation and rehydration of *Psidium guajava*," *Agronomía Costarricense*, vol. 43, pp. 107–121, 2019.

[15] T. O’Hare, J. Bagshaw, and W. L. G. Johnson, "Storage of oriental bunching onions. Post harvest handling of fresh vegetables," in *Proceedings of a Workshop on Oriental Vegetables*, FEPAF, Botucatu, Brazil, 2011.

[16] S. Pukacka, E. Ratajczak, and E. Kalemba, "Non reducing sugar levels in beech (*Fagus sylvatica*) seeds as related to conditioning temperature and period," *Seed Science & Technology*, vol. 30, no. 1, pp. 195–243, 2014.

[17] H. W. Pritchard, J. F. Moat, J. B. Ferraz et al., "Innovative approaches to the preservation of forest trees," *Forest Ecology and Management*, vol. 333, pp. 88–98, 2014.

[18] T. A. D. S. Smaniotto, O. Resende, K. A. F. Marçal, D. E. C. D. Oliveira, and G. A. Simon, "Qualidade fisiológica das sementes de soja armazenadas em diferentes condições," *Revista Brasileira de Engenharia Agrícola e Ambiental*, vol. 18, no. 4, pp. 446–453, 2014.

[19] J. D. Bewley, "Physiological aspects of desiccation tolerance," *Annual Review of Plant Physiology*, vol. 30, no. 1, pp. 195–238, 1979.

[20] C. Leopold, *Membranes, Metabolism and Dry Organisms*, Comstock Pub, London, UK, 1986.

[21] FAO (Food and Agriculture Organization), *Materiables para capacitación en semillas—Módulo 6: Almacenamiento de semillas, FAO*, Roma, Italia, 2019.

[22] T. Hong, S. Linington, and R. Ellis, *Compendium of Information on Seed Storage Behaviour*, The Royal Botanical Gardens Kew, Reino Unido, UK, 1998.

[23] F. R. Hay and R. J. Probert, "Advances in seed conservation of wild plant species: a review of recent research," *Conservation Physiology*, vol. 1, 2013.

[24] J. C. Delouche, R. K. Matthes, G. M. Dougherty, and A. H. Boyd, "Storage of seed in subtropical and tropical region," *Seed Science & Technology*, vol. 1, pp. 671–700, 1973.

[25] J. E. Guevara-Ohara, C. I. Cardozo-Conde, and L. G. Santos-Meléndez, "Tolerance to the desiccation and rehydration of *Psidium guajava*," *Agronomía Costarricense*, vol. 43, pp. 107–121, 2019.

[26] R. H. Ellis, T. D. Hong, and E. H. Roberts, "Moisture content and the longevity of seeds of Phaseolus vulgaris," *Annals of Botany*, vol. 66, no. 3, pp. 341–348, 1990.

[27] E. Muller, E. J. Cooper, and I. G. Alsos, "Germinability of arctic plants is high in perceived optimal conditions but low in the field," *Botany*, vol. 89, no. 5, pp. 337–348, 2011.

[28] C. W. Vertucci, E. E. Roos, and J. Crane, "Theoretical basis of protocols for seed storage—III. optimum moisture contents for pea seeds stored at different temperatures," *Annals of Botany*, vol. 74, no. 5, pp. 531–540, 1994.

[29] E. H. Roberts, "Predicting the storage life of seeds," *Seed Science & Technology*, vol. 1, pp. 499–514, 1973.

[30] A. J. Bekele, D. Obeng-Ofori, and A. Hassanali, "Evaluation of ochratoxin a (ayobangira) as a source of repellents toxicants and protectants in storage against three major stored product insect pests," *Journal of Applied Entomology*, vol. 121, pp. 169–173, 1997.

[31] A. A. Surki, F. Sharifizadeh, and R. T. Afshari, "Effect of drying conditions and harvest time on soybean seed viability and deterioration under different storage temperatures," *African Journal of Agricultural Research*, vol. 7, pp. 5118–5127, 2012.

[32] M. J. V. Hezewijk, A. P. V. Beem, J. A. C. Verkleij, and A. H. Pieterson, "Germination of *Orobanche crenata* seeds, as influenced by conditioning temperature and period," *Canadian Journal of Plant Science*, vol. 71, no. 6, pp. 786–792, 1993.
[45] S. Nasreen, B. R. Khan, and A. S. Mohmmd, “The effect of storage temperature, storage period and seed moisture content on seed viability of soybean,” Pakistan Journal of Biological Sciences, vol. 3, 2000.

[46] D. K. Ray, J. S. Gerber, G. K. MacDonald, and P. C. West, “Climate variation explains a third of global crop yield variability,” Nature Communications, vol. 6, no. 1, p. 5989, 2015.

[47] L. Schmidt, Guide to Handling of Tropical and Subtropical Forest Seeds, Dandia Forest Seed Centre, Borch Tyrk A/S, Denmark, 2002.

[48] G. Y. Zhang, S. C. Bahn, G. L. Wang et al., “PLDα,” Nature Communications, vol. 6, no. 1, p. 5989, 2015.

[49] J. F. Harrington, “Seed storage and longevity,” in Seed Biology, Insects, and Seed Collection, Storage, Testing, and Certification. Physiological Ecology. A Series of Monographs, Texts, and Treatise, T. T. Kozlowski, Ed., pp. 145–245, Academic Press, London, UK, 1972.

[50] J. D. Bewley, K. J. Bradford, H. W. M. Hilhorst, and H. Nonogaki, Seeds: Physiology of Development, Germination and Dormancy, Springer, Berlin, Germany, 2013.

[51] G. Mazza and D. S. Jayas, “Equilibrium moisture characteristics of sunflower seeds, hulls, and kernels,” Transactions of the ASAE, vol. 34, no. 2, pp. 0534–0538, 1991.

[52] C. M. Christensen and H. H. Kaufmann, “Deterioration of stored grains by fungi,” Annual Review of Phytopathology, vol. 3, no. 1, pp. 69–84, 1965.

[53] M. C. P. Yioti, “Seed deterioration: a review,” International Journal of Life Sciences Biotechnology and Pharma Research, vol. 2, pp. 374–385, 2013.

[54] R. B. Maude, Seed-borne Diseases and Their Control: Principles and Practice, CAB International, Wallingford, UK, 1997.

[55] R. C. Dumlao and M. B. Parker, “The influence of cold storage conditions on the viability of rice and corn seeds,” Philippine Agriculturist, vol. 44, pp. 327–337, 1960.

[56] M. O. Moss, “Economic importance of mycotoxins-recent incidence,” International Biodeterioration, vol. 27, no. 2, pp. 195–204, 1991.

[57] V. K. Agarwal and J. B. Sinclair, Principles of Seed Pathology, CRC Press, Boca Raton FL, USA, 1987.

[58] O. Alonso, A. Delgado, and S. Sánchez, “Hongos asociados a las semillas de una leguminosa tropical (Leucaena leucocephala cv. Perú),” Pastos Y Forrajes, vol. 19, pp. 161–168, 1996.

[59] J. C. Lecano, M. Navarro, Y. González, and O. Alonso, “Determinación de la calidad de las semillas de Leucaena leucocephala cv,” Perú almacenadas al ambiente, vol. 30, p. 1, 2007.

[60] M. M. C. Zamora, R. J. M. Torres, and L. I. Zamora-Martínez, Análisis de la Información Sobre Productos Forestales No Madereros En México, FAO, Santiago de Chile, Chile, 2001.

[61] MP. Colunga-Garcia, D. Zizumbo-Villarreal, and J. Martinez-Torres, “Tradiciones en el aprovechamiento de los agaves mexicanos: una aportación a su protección legal y conservación biológica y cultural,” En lo ancestral hay futuro: del tequila, los mezcales y otros agaves, CICY-CONACYT-CONABIO-INE, Mexico, 2007.

[62] X. Aguirre-Dugua and L. Euguiarte, “Genetic diversity, conservation and sustainable use of wild agave cupreata and agave potatorum extracted for mezcal production in Mexico,” Journal of Arid Environments, vol. 90, pp. 36–44, 2013.

[63] I. Torres, J. Blancas, A. León, and A. Casas, “TEK, local perceptions of risk, and diversity of management practices of agave inaquinids in Michoacán, México,” Journal of Ethnobiology and Ethnomedicine, vol. 11, no. 1, p. 61, 2015.

[64] S. V. Wyse and J. B. Dickie, “Predicting the global incidence of seed desiccation sensitivity,” Journal of Ecology, vol. 105, no. 4, pp. 1082–1093, 2017.

[65] P. W. Winston and D. H. Bates, “Saturated solutions for the control of humidity in biological research,” Ecology, vol. 41, no. 1, pp. 232–237, 1960.

[66] ISTA, “International rules for seed testing,” 2004, https://https://rngr.net/publications/manual-de-semillas-de-arboles-tropicales/parte-i-semillas-or-odoxas-y-recalcitrantes/at_download/file.

[67] J. H. Schmidt, Guide to Handling of Tropical and Subtropical Forest Seed, Dandia Forest Seed Centre, Hoersholm, Denmark, 2000.

[68] J. D. Bewley and M. Black, Seeds: Physiology of Development and Germination, Plenum Press, New York, NY, USA, 1994.

[69] M. I. Daws, N. C. Garwood, and H. W. Pritchard, “Traits of recalcitrant seeds in a semi-deciduous tropical forest in Panamá: some ecological implications,” Functional Ecology, vol. 19, no. 5, pp. 874–885, 2005.

[70] K. J. Bradford, Seed Production and Quality, University of California, Davis, CA, USA, 1st edition, 2004.

[71] C. C. Gómez, Long Term Seed Preservation: The Risk of Selecting Inadequate Containers is Very High, Universidad Politécnica de Madrid, Madrid, Spain, 2002.

[72] W. Roca, D. Arias, and R. Chávez, “Métodos de conservación en vitro del germoplasma,” in Cultivo de tejidos en la Agricultura, W. Roca and L. Mrogrinski, Eds., CIAT, Cali, Colombia, 1991.

[73] A. Sandoval, Notas del Centro de Semillas y Árboles Forestales, Universidad de Chile, Santiago,Chile, 2004.

[74] M. M. L. Flores and L. W. Acosta, “Conservació de los Recursos Genéticos de la agrobiodiversidad,” Info INIAF, vol. 1, pp. 86–90, 2013.

[75] FAO (Food and Agriculture Organization), Global Plan of Action for the Conservation and Sustainable Utilization of Plant Genetic Resources for Food and Agriculture, and Leipzig Declaration, Food and Agriculture Organization of the United Nations, Rome, Italy, 1996.

[76] F. Camacho, Dormición de semillas: causas y tratamientos, Editorial Trillas, México, 1994.

[77] M. A. García, México, país de magueyes. La Jornada del Campo. Núm 53. Suplemento, La Jornada, México, 2012.

[78] E. Matos, M. Marcano, C. Azócar, and A. Mora, “Esta- blecimiento y multiplicación in vitro de cinco cultivares de Apio (Arracacia xanthorrhiza) Bancroft) colectados en Ven- ezuela,” Bioagro, vol. 27, pp. 121–130, 2015.

[79] G. Scott, M. Rosegrant, and C. Ringerl, Raíces y tubérculos para el siglo 21: Tendencias, proyecciones y opciones de política, Instituto Internacional de Investigación sobre Políticas Alimentarias, Washington, DC, USA, 2000.
Q. D. Castillo and R. J. T. Saenz, "Tarifa de Rendimiento De Cortadillo (Nolina Cespitifera Trel.) para el sur de Coahuila. INIFAP-CIRNE, Campo Experimental Saltillo, Coahuila, Mexico, 2005.

J. T. Saenz and D. Q. Castillo, "Guía para la evaluación del cortadillo en el Estado de Coahuila. Folleto Técnico No. 3. Campo Experimental La Sauceda, INIFAP-CIRNE, Saltillo, Mexico, 1992.

O. Koksal, E. Gunes, O. Orkan, and M. Ozden, "Analysis of effective factor on information sources at Turkish oregano farms," African Journal of Agricultural Research, vol. 5, pp. 142–149, 2015.

R. A. Corella-Bernal and M. M. Ortega-Nieblas, "Importancia del aceite esencial y la producción de orégano lippia palmeri watson en el estado de Sonora," Biotecnia, vol. 15, no. 1, pp. 57–64, 2013.

U. Sacheti and M. S. Al-Areimi, "The influence of high storage and germination temperatures on the germination of Prosoips cineraria seeds from northern Oman," Journal of Tropical Forest Science, vol. 12, pp. 191–193, 2000.

N. Aligiannis, E. Kalpoutzakis, S. Mitaku, and I. B. Chinou, "Composition and antimicrobial activity of the essential oils of two Origanum species," Journal of Agricultural and Food Chemistry, vol. 49, no. 9, pp. 4168–4170, 2001.

G. Vadillo, M. Suni, and A. Cano, "Viabilidad y germinación de semillas de Puya raimondii Harms (Bromeliaceae)," Revista Peruana de Biologia, vol. 11, no. 1, pp. 71–78, 2013.

N. Buitrago-Rueda, M. Ramirez-Villalobos, A. Gomez-Degraves, G. Rivero-Maldonado, and A. Perozo-Bravo, "Efecto del almacenamiento de las semillas y la condición de luz possiembra sobre la germinación y algunas características morfológicas de plantas de níspero (Manilkara zapota (L.) P. Royen) a nivel de vivero," Revista de la Facultad de Agronomía, vol. 21, pp. 343–352, 2004.

G. A. Vega, A. E. Lara, and M. R. Lemus, "Isotermas de adsorción en harina de maíz," Ciencia e Tecnologia de Alimentos, vol. 26, pp. 821–827, 2006.

A. A. Abdul-Bak and J. D. Anderson, "Physiological and biochemical deterioration of seed," Seed Biology, Academic Press, New York, NY, USA, 1972.

F. T. Bonner, J. A. Vozzo, W. W. Elam, and S. B. Land, "Tree seed technology training course," Instructor’s Manual, USDA, Forest Service, New Orleans, LO, USA, 1994.

H. H. Schawartz and M. A. Pastor-Corrales, Bean Production Problem, CIAT, Cali, Colombia, 1980.

R. H. Ellis, T. D. Hong, D. Astley, A. E. Pinnegar, and H. L. Kraak, "Survival of dry and ultra-dry seeds of carrot, groundnut, lettuce, oilseed rape, and onion during five years’ hermetic storage at low temperatures," Seed Science & Technology, vol. 24, pp. 347–358, 1996.

O. L. Copeland and M. B. McDonald, Principles of Seed Science and Technology, Kluwer Press, New York, NY, USA, 2001.

K. Bradford and H. Nonogaki, Seed Development, Dormancy and Germination, Blackwell Publishing, Hoboken, NJ, USA, 2007.

C. V. Castro, P. R. Eyzaguire, and S. A. Ceroni, "Survival of melocactus peruvianus vaupel and haageocereus pseudo-melanostele subsp. aureispinus (rauh & backeberg) ostolaza. plants at umarcata hill, chillon river valley, Lima," Ecologia Aplicada, vol. 5, pp. 61–66, 2006.

F. A. Lazzari, Umidade, fungos e micotoxinas na qualidade de sementes, grãos e rações, Edição do autor, Curitiba, Brazil, 1993.