P.ISSN: 0971-8184 II E ISSN: 0976-1926
DOI: https://doi.org/10.56093/ijpgr.v39i3.184706

Indian Journal of Plant Genetic Resources

RESEARCH ARTICLE

Assessment of Seed Morphometric Variability in Six Bamboo Species Using Digital Image Analysis

Manish Kumar Vijay[1]*, Deependra Malviya[1], Shweta Tiwari[1] and Lata Kahar[1]

Abstract

Bamboo seed availability is often constrained by irregular flowering and sporadic seed production, making characterization of available seed material important for germplasm conservation and propagation. The present study assessed seed morphometric variability in six bamboo species, *Bambusa bambos*, *B. polymorpha*, *B. tulda*, *Dendrocalamus latiflorus*, *D. longispathus* and *D. strictus*, using digital image analysis. Seed area, length, width, aspect ratio, diameter, perimeter and roundness were measured using the Biovis Seed Image Analyzer. Considerable interspecific variation was observed in all measured parameters. *B. tulda* exhibited the largest seed area, length and aspect ratio, whereas *D. longispathus* showed the smallest seed dimensions. Digital image analysis provided rapid and non-destructive quantitative characterization of bamboo seeds. The generated morphometric profiles may support seed identification, germplasm characterization and conservation.

Keywords: Bamboo, Digital image analysis, Germplasm conservation, Seed characterization, Seed morphometry

[1]ICFRE-Tropical Forest Research Institute, Jabalpur, Madhya Pradesh, 482001, India

***Author for correspondence:**
manishvijay89@gmail.com

Received: 28/01/2025

Revised: 03/10/2026

Accepted: 06/10/2026

How to cite this article: Manish Kumar Vijay, Deependra Malviya, Shweta Tiwari and Lata Kahar (2026) Assessment of Seed Morphometric Variability in Six Bamboo Species Using Digital Image Analysis. *Indian J. Plant Genet. Resour.* 39(3): 81-87.

DOI: https://doi.org/10.56093/ijpgr.v39i3.184706

Introduction

Bamboo is an ecologically and economically important group of plants owing to its rapid growth, adaptability and diverse applications in construction, furniture, food, handicrafts and ecological restoration. Bamboo belongs to the family Poaceae and comprises approximately 121 genera and 1,662 species worldwide, with major diversity and utilization in South, Southeast and East Asia (Canavan *et al.*, 2016). In India, bamboo supports rural livelihoods and has diverse traditional and industrial uses (Mehra and Mehra, 2007). Increasing demand for bamboo resources emphasizes the need for effective conservation, propagation and sustainable management of bamboo genetic resources (ISFR, 2021).

A major constraint to the conservation and propagation of bamboo is its unusual reproductive behaviour. Flowering in many bamboo species occurs at long and irregular intervals, resulting in unpredictable seed availability. Some species, such as *Bambusa balcooa* and *Bambusa vulgaris*, rarely produce seeds, whereas *Bambusa bambos* and *Dendrocalamus strictus* may flower after intervals of several decades, often followed by mortality of the parent plants (Roy *et al.*, 2014). Sporadic seed production and limited seed availability consequently restrict seed-based propagation and the systematic characterization and conservation of bamboo germplasm.

© IJPGR, 2025. Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit https://creativecommons.org/licenses/by-nc-sa/4.0/.

Seed morphology provides useful quantitative information for species characterization and differentiation. Traits such as seed length, width, area and shape can vary among taxa and populations and serve as useful descriptors for germplasm characterization (Saatkamp *et al.*, 2019). Conventional measurement using callipers is relatively laborious and may be influenced by operator handling. Digital image analysis provides a rapid, non-destructive and reproducible approach for measuring seed morphological attributes (Dell'Aquila, 2006; Tanabata *et al.*, 2012; Kapadia *et al.*, 2017). Image-based methods enable simultaneous measurement of multiple size- and shape-related traits and have been applied for seed characterization and differentiation in agricultural and forest species (Bianco *et al.*, 2016; Felix *et al.*, 2023; Jannah *et al.*, 2024).

Despite the ecological and economic importance of bamboo, quantitative information on seed morphometric variation among bamboo species remains limited. Comparative characterization of seed size and shape can provide baseline information for species identification, germplasm documentation and conservation. Digital image analysis is particularly useful for characterizing limited seed material obtained from species with irregular and infrequent flowering.

Therefore, the present study aimed to assess and compare seed morphometric variability among six bamboo species—*Bambusa bambos*, *Bambusa polymorpha*, *Bambusa tulda*, *Dendrocalamus latiflorus*, *Dendrocalamus longispathus* and *Dendrocalamus strictus*—using digital image analysis. Seed area, length, width, aspect ratio, diameter, perimeter and roundness were evaluated to characterize species-level variation in seed size and shape and to generate baseline morphometric information for bamboo seed identification and germplasm conservation.

Materials and Methods

Study species and seed sampling

Six bamboo species, namely *Bambusa bambos*, *Bambusa polymorpha*, *Bambusa tulda*, *Dendrocalamus latiflorus*, *Dendrocalamus longispathus* and *Dendrocalamus strictus*, were selected for the study based on their ecological and economic importance. Seeds were collected from mature bamboo plants within their respective native ranges. Uniform and healthy seeds were selected to minimize experimental variation during image acquisition and morphometric analysis.

For each species, 100 seeds were evaluated in five replications, with 20 seeds per replication. Thus, a total of 600 seeds representing six bamboo species were analysed.

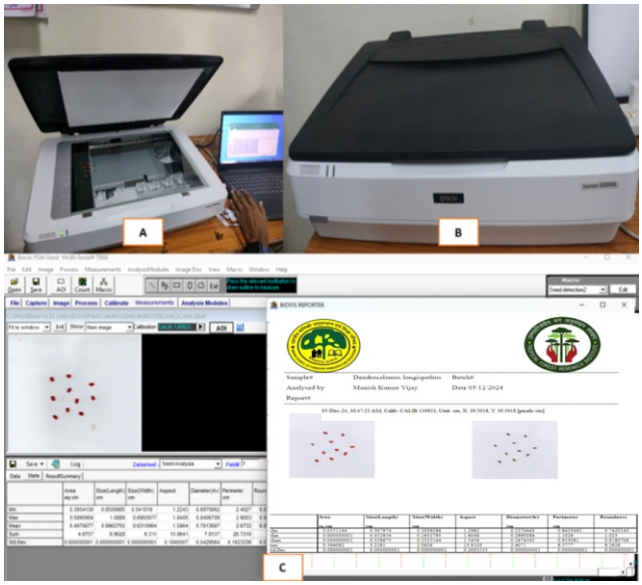


Fig. 1: Seed image analysis workflow showing (A) placement of seeds on the flatbed scanner, (B) acquisition of standardized seed images, and (C) analysis of individual seed images using the Biovis Seed Image Analysis System. The workflow illustrates the sequential acquisition and digital measurement of individual seed morphometric characteristics.

Seed image acquisition and processing

Seeds were scanned using a Biovis Seed Image Analysis System equipped with an Epson Expression 12000XL high-resolution flatbed scanner. The scanner uses a 6-line CCD sensor with an optical resolution of 2400 × 4800 dpi. Images were acquired at a standardized resolution of 600 dpi under uniform scanning conditions. For each replication, 20 seeds were systematically arranged on the scanner bed with sufficient separation to facilitate individual seed detection and measurement. The scanned images were subsequently analysed using the Biovis seed image analysis software to obtain seed morphometric parameters, including length, width, area, perimeter, circularity, aspect ratio and other shape descriptors (Fig. 1).

Morphometric parameters

The Biovis software was used to analyse the scanned binary seed images and quantify the following morphometric parameters:

1. Area: Total area of the segmented seed region.
2. Length: Longest traceable dimension of the seed outline.
3. Width: Dimension of the seed measured

perpendicular to its longitudinal axis.

4. Aspect ratio: Ratio representing the relative elongation of the seed.
5. Diameter: Equivalent diameter calculated by the software from the seed region.
6. Perimeter: Total length of the detected seed boundary.
7. Roundness/circularity: A shape-related descriptor calculated by the Biovis software from the segmented seed image.

These parameters were used to characterize differences in seed size and shape among the six bamboo species.

Image analysis and calibration

The scanned images were processed using the Biovis seed image analysis software under standardized analysis conditions. The software automatically detected individual seed boundaries and generated quantitative measurements for the selected morphometric parameters. The same imaging and analysis settings were maintained for all samples to ensure comparability among species.

Statistical analysis

For each species, observations from five replications of 20 seeds each were used to calculate the mean and standard error (SE) for each morphometric parameter. The resulting descriptive statistics were used to characterize and compare interspecific variation in seed size and shape.

Results and Discussion

Morphometric characteristics of the studied bamboo species

The six bamboo species differed in their seed size and shape based on the morphometric parameters obtained through digital image analysis (Fig. 2). A total of 100 seeds per species, comprising five replications of 20 seeds each, were analysed. The measured parameters included seed area, length, width, aspect ratio, diameter, perimeter and roundness. As the present analysis was based on descriptive statistics, the observed differences are interpreted as interspecific variation and are not described as statistically significant.

The six bamboo species evaluated in the present study represented two genera, *Bambusa* and *Dendrocalamus*, and differed in their habitat preferences and major uses (Table 1). These characteristics provide background information on the studied species but were not

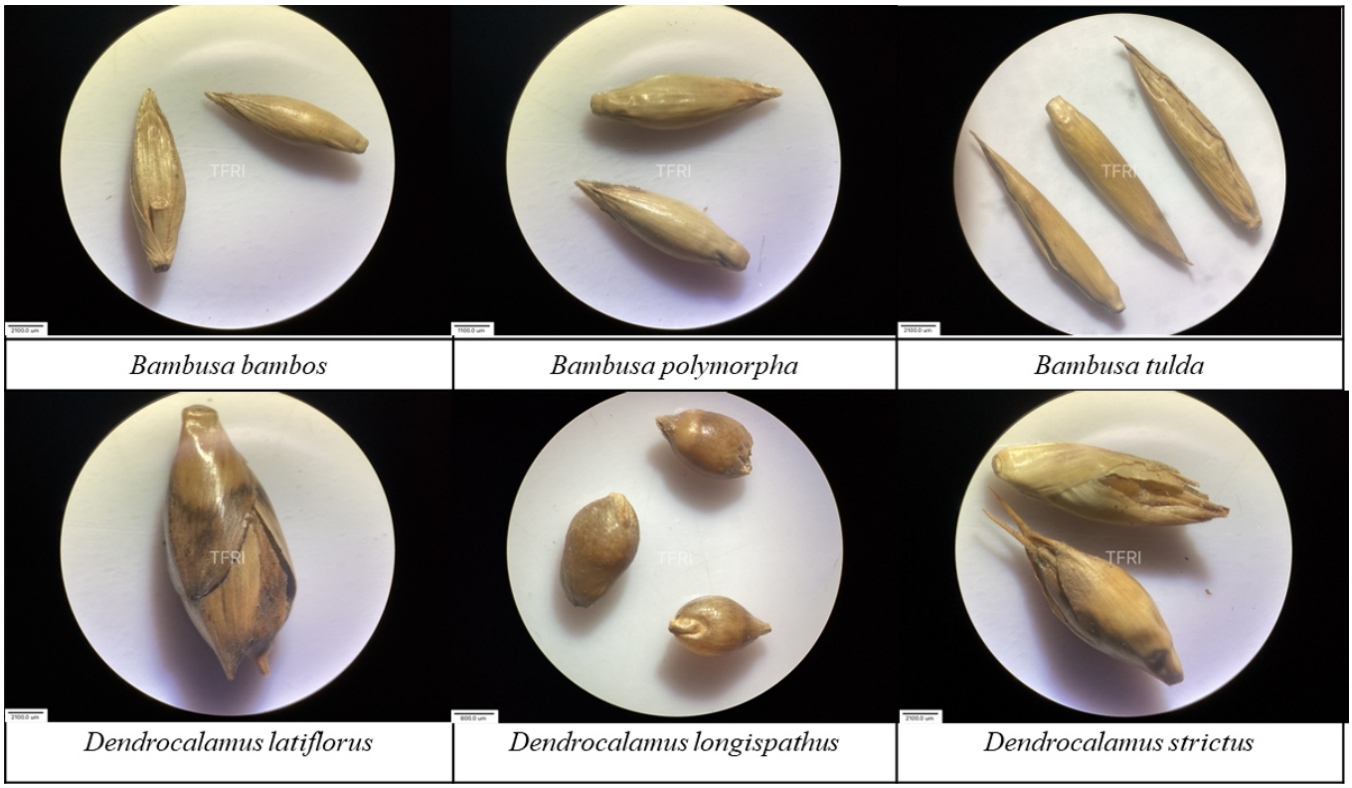


Fig. 2: Representative seed images illustrating morphometric diversity among *Bambusa bambos*, *Bambusa polymorpha*, *Bambusa tulda*, *Dendrocalamus latiflorus*, *Dendrocalamus longispathus* and *Dendrocalamus strictus*.
Scale bar = 2100 µm (2.1 mm) in all panels.

Table 1. Brief overview of the six bamboo species studied in the present investigation

S. No.	Species	Common name	Preferred habitat	Major uses
1	*Bambusa bambos*	Common Bamboo / Thorny Bamboo	Tropical and subtropical regions; well-drained soils with high rainfall	Construction, handicrafts, paper pulp, edible shoots and soil conservation
2	*Bambusa polymorpha*	Burma Bamboo	Moist tropical forests; prefers sandy loam soils	Construction, furniture, edible shoots, paper and scaffolding
3	*Bambusa tulda*	Indian Timber Bamboo	Subtropical and humid regions; well-drained, fertile soils	Paper, construction, baskets, mats, furniture and musical instruments
4	*Dendrocalamus latiflorus*	Taiwan Giant Bamboo	Warm and humid regions; well-drained, fertile soils	Edible shoots, construction, handicrafts and paper pulp
5	*Dendrocalamus longispathus*	Long-spiked Bamboo	Tropical lowlands; moist, loamy soils	Construction, paper, baskets, mats and fodder
6	*Dendrocalamus strictus*	Male Bamboo / Solid Bamboo	Arid and semi-arid regions; tolerant of poor soils and drought	Furniture, construction, paper, scaffolding, bioenergy and soil conservation

Source: Morphometric ranges, habitat distributions and silvicultural characteristics compiled from Seethalakshmi and Kumar (1998), Tewari (1992), Flora of China Editorial Committee (2006) and Banik (2016). The information in this table is descriptive and was not included as a variable in the statistical analysis.

included as variables in the morphometric analysis.

Bambusa bambos recorded a mean seed area of 0.1138 ± 0.0052 cm^2, length of 0.6706 ± 0.0106 cm and width of 0.2201 ± 0.0117 cm. The corresponding values for aspect ratio, diameter, perimeter and roundness were 3.0759 ± 0.1170, 0.4047 ± 0.0114 cm, 1.5103 ± 0.0262 cm and 0.6254 ± 0.0142, respectively. *Bambusa polymorpha* showed somewhat larger mean seed dimensions, with an area of 0.1669 ± 0.0183 cm^2, length of 0.8279 ± 0.0257 cm and width of 0.2988 ± 0.0503 cm. Its mean aspect ratio, diameter, perimeter and roundness were 3.1056 ± 0.2692, 0.4900 ± 0.0192 cm, 1.9589 ± 0.0750 cm and 0.5349 ± 0.0216, respectively.

Among the six species, *Bambusa tulda* recorded the highest mean seed area (0.8704 ± 0.0346 cm^2), length (2.5181 ± 0.0615 cm), aspect ratio (5.0633 ± 0.2157), diameter (1.2674 ± 0.0295 cm) and perimeter (5.7556 ± 0.1341 cm). Its mean width was 0.5005 ± 0.0182 cm, and roundness was 0.3301 ± 0.0070. The high aspect ratio, together with the comparatively low roundness value, indicates a distinctly elongated seed shape. Quantitative seed dimensions and shape descriptors have similarly been used to characterize variation among plant taxa and seed lots (Costa *et al.*, 2016; Correia *et al.*, 2019; Felix *et al.*, 2020, 2023). Such measurements can provide useful baseline descriptors for germplasm characterization when combined with appropriate taxonomic and biological information.

Dendrocalamus latiflorus recorded a mean seed area of 0.5537 ± 0.0236 cm^2, length of 1.3851 ± 0.0410 cm and width of 0.5773 ± 0.0120 cm. Its aspect ratio was 2.4038 ± 0.0756, while the mean diameter and perimeter were 0.8831 ± 0.0247 cm and 3.4104 ± 0.0860 cm, respectively. The mean roundness value was 0.5976 ± 0.0096. These measurements placed *D. latiflorus* between the larger-seeded *B. tulda* and the smaller-seeded species for several of the measured parameters.

Dendrocalamus longispathus recorded the lowest mean values for seed area (0.0380 ± 0.0053 cm^2), length (0.2613 ± 0.0218 cm), width (0.1601 ± 0.0109 cm), diameter (0.1955 ± 0.0143 cm) and perimeter (0.6795 ± 0.0626 cm). Its aspect ratio was 1.6286 ± 0.0278, the lowest among the six species. The software-derived roundness value was 1.0337 ± 0.0482. The contrasting values between *B. tulda* and *D. longispathus* demonstrate the extent of variation in both seed size and shape within the studied material.

Dendrocalamus strictus showed intermediate values for several morphometric characteristics, with a mean seed area of 0.3426 ± 0.0324 cm^2, length of 1.2415 ± 0.0534 cm and width of 0.4124 ± 0.0301 cm. Its mean aspect ratio was 3.0685 ± 0.1587, while diameter, perimeter and roundness were 0.7137 ± 0.0294 cm, 3.1093 ± 0.2629 cm and 0.4624 ± 0.0335, respectively. The species therefore displayed a morphometric profile intermediate between the smaller-seeded *D. longispathus* and the larger-seeded *B. tulda* for several traits.

Across the six species, mean seed area ranged from 0.0380 cm^2 in *D. longispathus* to 0.8704 cm^2 in *B. tulda*. Mean seed length ranged from 0.2613 to 2.5181 cm, while mean width ranged from 0.1601 to 0.5773 cm. The aspect ratio ranged from 1.6286 to 5.0633, whereas mean diameter and perimeter ranged from 0.1955 to 1.2674 cm and 0.6795 to 5.7556 cm, respectively. The software-derived roundness values ranged from 0.3301

in *B. tulda* to 1.0337 in *D. longispathus* (Table 2). The combination of these parameters provides a quantitative morphometric profile for each species and demonstrates the usefulness of digital imaging for documenting seed-level variation.

Digital image analysis and species characterization

The observed variation in seed morphology is consistent with the broader application of digital image analysis for quantitative seed characterization. Image-based approaches allow several morphological attributes to be measured simultaneously and reduce the operator dependence associated with conventional manual measurements. Computer-assisted seed imaging has been applied to evaluate seed characteristics and physiological potential, while digital morphometrics has also been used for species differentiation and high-throughput phenotyping (Dell'Aquila, 2004, 2006; Chiquito *et al.*, 2012; Pontes *et al.*, 2018). Seed image analysis has further been applied for morpho-colourimetric characterization and differentiation among plant taxa (Bianco *et al.*, 2016; Felix *et al.*, 2023; Jannah *et al.*, 2024).

In the present study, the largest overall morphometric values were recorded for *B. tulda*, whereas *D. longispathus* showed the smallest values for most size-related parameters. The simultaneous assessment of area, linear dimensions and shape descriptors therefore provided greater discrimination than reliance on a single seed measurement. Such an approach may be particularly useful for bamboo germplasm because irregular flowering and limited seed availability can make repeated conventional measurements of valuable seed lots difficult.

The observed morphometric differences should, however, be interpreted primarily as physical descriptors rather than direct indicators of physiological quality, vigour or ecological adaptation. Seed traits may vary among populations and may be influenced by maternal plant characteristics and environmental conditions during seed development. Seed-trait studies have emphasized the importance of considering variation in seed characteristics within an ecological and developmental context (Saatkamp *et al.*, 2019). Therefore, the present results provide a baseline for morphological characterization but should not be used alone to infer differences in germination, viability, seedling establishment or storage behaviour.

Roundness and interpretation of software-derived parameters

The roundness parameter requires particular consideration because the value recorded for *D. longispathus* (1.0337 ± 0.0482) exceeds unity. This value should not be interpreted as a conventional normalized circularity index. Instead, it should be reported as the roundness parameter generated by the Biovis Seed Image Analysis System. The exact mathematical formulation of the software-derived parameter should be provided if it is available in the manufacturer's documentation. If the formulation is proprietary or unavailable, comparisons should be restricted to values generated under identical software and image-analysis conditions.

This clarification is important for reproducibility because different image-analysis systems may use

Table 2. Seed morphometric characteristics of six bamboo species determined using digital image analysis

S. No.	Species	Area (cm^2) Mean ± SE	Length (cm) Mean ± SE	Width (cm) Mean ± SE	Aspect ratio Mean ± SE	Diameter (cm) Mean ± SE	Perimeter (cm) Mean ± SE	Roundness Mean ± SE
1	Bambusa bambos	0.1138 ± 0.0052	0.6706 ± 0.0106	0.2201 ± 0.0117	3.0759 ± 0.1170	0.4047 ± 0.0114	1.5103 ± 0.0262	0.6254 ± 0.0142
2	Bambusa polymorpha	0.1669 ± 0.0183	0.8279 ± 0.0257	0.2988 ± 0.0503	3.1056 ± 0.2692	0.4900 ± 0.0192	1.9589 ± 0.0750	0.5349 ± 0.0216
3	Bambusa tulda	0.8704 ± 0.0346	2.5181 ± 0.0615	0.5005 ± 0.0182	5.0633 ± 0.2157	1.2674 ± 0.0295	5.7556 ± 0.1341	0.3301 ± 0.0070
4	Dendrocalamus latiflorus	0.5537 ± 0.0236	1.3851 ± 0.0410	0.5773 ± 0.0120	2.4038 ± 0.0756	0.8831 ± 0.0247	3.4104 ± 0.0860	0.5976 ± 0.0096
5	Dendrocalamus longispathus	0.0380 ± 0.0053	0.2613 ± 0.0218	0.1601 ± 0.0109	1.6286 ± 0.0278	0.1955 ± 0.0143	0.6795 ± 0.0626	1.0337 ± 0.0482
6	Dendrocalamus strictus	0.3426 ± 0.0324	1.2415 ± 0.0534	0.4124 ± 0.0301	3.0685 ± 0.1587	0.7137 ± 0.0294	3.1093 ± 0.2629	0.4624 ± 0.0335

Note: Values represent mean ± SE based on 100 seeds per species (five replications × 20 seeds). Area is expressed in cm^2; length, width, diameter and perimeter are expressed in cm. Roundness represents the value generated by the Biovis Seed Image Analysis System and should not be interpreted as a standardized circularity index without reference to the software's mathematical definition.

different definitions of roundness, circularity or shape descriptors. Accordingly, the roundness values reported here should be interpreted as software-derived descriptors of seed shape rather than as universally standardized circularity values.

Implications for bamboo germplasm characterization and conservation

The morphometric profiles generated in the present study provide baseline information for documenting the six bamboo species. Digital image analysis permits rapid, non-destructive measurement and digital archiving of seed characteristics, which may be useful for accession documentation, preliminary identification and comparative characterization of bamboo germplasm. The approach can complement conventional taxonomic observations and, where required, physiological seed testing.

The results should nevertheless be considered within the limitations of the present sampling design. Seeds were evaluated from the available material, and the study did not assess multiple provenances or populations within each species. Consequently, the observed differences cannot be used to separate the effects of species identity from possible provenance- or environment-related variation. Further studies involving multiple seed sources, larger populations and repeated collections would help determine the stability of the observed morphometric profiles. Integration of digital morphometric traits with seed moisture content, viability, germination, storage behaviour and molecular characterization could provide a more comprehensive framework for bamboo germplasm characterization and conservation.

Overall, digital image analysis successfully generated quantitative profiles of seed size and shape for the six bamboo species studied. The marked differences observed among species, particularly in seed area, length, aspect ratio, diameter and perimeter, demonstrate the utility of image-based morphometric characterization as a baseline tool for bamboo seed identification and germplasm documentation. The results also provide a foundation for subsequent studies integrating seed morphology with physiological and genetic attributes.

References

Alencar NE, AR Figueira, HO Santos and PSG Duarte (2016) Image analysis and physiological quality assessment of seeds produced in pumpkin plants infected with the squash mosaic virus (SqMV). *Res. J. Seed Sci.* 9(1): 14-21.

Banik RL (2016) *Silviculture and Uses of Bamboos*. Springer, Singapore. https://doi.org/10.1007/978-981-10-0569-5

Bianco ML, O Grillo, PE Garcia, F Mascia, G Venora and G Bacchetta (2016) Morpho-colorimetric characterization of Malva alliance taxa by seed image analysis. *Plant Biol.* 19(1): 1-9. https://doi.org/10.1111/plb.12481

Canavan S, DM Richardson, V Visser, JJ Roux, MS Vorontsova and JR Wilson (2016) The global distribution of bamboos; Assessing correlates of introduction and invasion. *AoB Plants* 9: 78.

Chiquito AA, FG Gomes-Junior and J Marcos-Filho (2012) Assessment of physiological potential of cucumber seeds using the software Seedling Vigour Imaging System® (SVIS®). *Rev. Bras. Sementes* 34(2): 255-63. https://doi.org/10.1590/S0101-31222012000200010

Correia LAS, FC Felix, FDS Araujo, CDS Ferrari and MV Pacheco (2019) Morphometric descriptors and physiological seed quality for selecting *Aspidosperma pyrifolium* Mart. matrix trees. *Rev. Caatinga* 32(3): 751-9. https://doi.org/10.1590/1983-21252019v32n319rc

Costa MF, ACA Lopes, RLF Gomes, ASF Araújo, MI Zucchi, JB Pinheiro and SES Valente (2016) Characterization and genetic divergence of *Casearia grandiflora* populations in the Cerrado of Piaui State, Brazil. *Floresta Ambient.* 23(3): 387-96. https://doi.org/10.1590/2179-8087.007115

Dell'Aquila A (2004) Application of a computer-aided image analysis system to evaluate seed germination under different environmental conditions. *Ital. J. Agron.* 8: 51-62.

Dell'Aquila A (2006) Computerised seed imaging; a new tool to evaluate germination quality. *Commun. Biom. Crop Sci.* 1(1): 20-31.

Desai S and AP Rao (2017) Seed quality analysis using image processing and ANN. *Int. J. Trend Sci. Res. Dev.* 1(4): 698-9. Available from: https://www.ijtsrd.com

Felix FC, JAD Medeiros, CS Ferrari, FA Vieira and MV Pacheco (2020) Biometry of *Pityrocarpa moniliformis* seeds using digital imaging; implications for studies of genetic divergence. *Rev. Bras. Ciênc. Agrár.* 15(1): 1-8. https://doi.org/10.5039/agraria.v15i1a6128

Felix FC, D Kratz, R Ribeiro and AC Nogueira (2023) Characterization and differentiation of forest species by seed image analysis; a new methodological approach. *Ciênc. Florest.* 33: e73427. https://doi.org/10.5902/1980509873427

Flora of China Editorial Committee (2006) Poaceae (Bambusoideae). In: ZY Wu, PH Raven and DY Hong (eds) *Flora of China*, Vol. 22. Science Press, Beijing and Missouri Botanical Garden Press, St. Louis.

Furbank RT and M Tester (2011) Phenomics–technologies to relieve the phenotyping bottleneck. *Trends Plant Sci.* 16(12): 635-44. https://doi.org/10.1016/j.tplants.2011.09.005

ISFR (2021) *India State of Forest Report 2021*. Forest Survey of India, Ministry of Environment, Forest and Climate Change, Kaulagarh Road, P.O. IPE, Dehradun, Uttarakhand, India.

Jannah RM, S Ratnawati, WB Suwarno and SW Ardie (2024) Digital phenotyping for robust seeds variability assessment in *Setaria italica* (L.) P. Beauv. *J. Seed Sci.* 46: e281586. https://doi.org/10.1590/2317-1545v46281586

Kapadia VN, N Sasidharan and P Kalyanrao (2017) Seed image analysis and its application in seed science research. *Int. J. Pure Appl. Biosci.* 5(2): 486-96. https://doi.org/10.18782/2320-7051.2721

Mehra SP and LK Mehra (2007) Bamboo cultivation–potential and prospects. *Tech. Dig.* 10. Available from:

https://www.nabard.org/pdf/BAMBOO.pdf [Accessed 17 December 2013].

Pontes MS, CV Montefusco-Pereira, BB Misra, HL Ribeiro-Junior, DE Graciano, JS Santos and EF Santiago (2018) High-throughput phenotyping by applying digital morphometrics and fluorescence induction curves in seeds to identifying variations; a case study of *Annona* (Annonaceae) species. *Inf. Process. Agric.* 5(4): 443-55. https://doi.org/10.1016/j.inpa.2018.07.001

Roy SS, MN Ali, S Gantait, S Chakraborty and M Banerjee (2014) Tissue culture and biochemical characterization of important bamboos. *Res. J. Agric. Sci.* 5(2): 135-46.

Saatkamp A, A Cochrane, L Commander, LK Guja, B Jimenez-Alfaro and J Larson (2019) A research agenda for seed-trait functional ecology. *New Phytol.* 221: 1764-75. https://doi.org/10.1111/nph.15502

Santana SH, SB Torres and CP Benedito (2013) Biometrics of fruits and seeds and germination of balsam pear. *Rev. Bras. Plant Med.* 15(2): 169-75. https://doi.org/10.1590/S1516-05722013000200001

Seethalakshmi KK and MSM Kumar (1998) *Bamboos of India; a Compendium*. Kerala Forest Research Institute (KFRI) and International Network for Bamboo and Rattan (INBAR), Peechi, India.

Tanabata T, T Shibaya, K Hori, K Ebana and M Yano (2012) SmartGrain; high-throughput phenotyping software for measuring seed shape through image analysis. *Plant Physiol.* 160(4): 1871-80. https://doi.org/10.1104/pp.112.205120

Tewari DN (1992) *A Monograph on Bamboo*. International Book Distributors, Dehradun, India.