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Use of the X-ray technique to evaluate the internal morphology of seeds of green manure species

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ABSTRACT: Image analysis through X-ray technique has been receiving great attention due to its importance in identifying internal damage in seeds quickly and accurately, in addition to being a non-destructive method. The aim of this study was to assess the use of X-rays to evaluate the internal morphology of seeds of green manure species. Seeds of *Lupinus albus* L., *Cajanus cajan* (L.) Millsp., *Canavalia ensiformis* (L.) DC. and *Stylosanthes* spp. were radiographed. Two hundred seeds were studied for each species, and intact seeds, seeds with mechanical damage, damage caused by insects and deteriorated tissues were recorded, considering the severity and location of the damage. The same seeds were subjected to a germination test. It was concluded that image analysis using X-ray technique was effective in detecting internal damage in seeds of some green manure species and it has relationship with negative aspects in germination.

Index terms: image analysis, germination, mechanical damage, radiography.

RESUMO: A análise de imagens por meio da técnica de raios X vem recebendo grande destaque por ser uma técnica importante para identificação de danos internos em sementes, de forma rápida e precisa, além de ser um método não destrutivo. O objetivo do trabalho foi verificar a utilização de raios x para avaliação da morfologia interna de sementes de espécies de adubos verdes. Sementes de tremoço-branco (*Lupinus albus* L.), feijão guandu-anão (*Cajanus cajan* (L.) Millsp.), feijão-de-porco (*Canavalia ensiformis* (L.) DC.) e estilosantes (*Stylosanthes* spp.) foram radiografadas, sendo estudadas 200 sementes para cada espécie e contabilizadas as sementes intactas e as com danos mecânicos, danos causados por insetos e tecidos deteriorados, considerando a severidade e localização dos danos. As mesmas sementes foram avaliadas pelo teste de germinação. Concluiu-se que a análise de imagens por meio da técnica de raios X é eficiente na detecção de danos internos em sementes das espécies de adubos verdes estudadas e apresenta relação com os aspectos negativos na germinação.

Termos para indexação: análise de imagens, germinação, danos mecânicos, radiografia.

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INTRODUCTION

Used for more than 2,000 years, green manuring is an agricultural practice capable of increasing crop production and contributes to protecting the soil against erosion and solar radiation, allows increasing its organic matter content and promotes soil decompaction, structuring and aeration, contributing to reducing dependence on external inputs and hence reducing the cost of production, with legume crops (Lima-Filho et al., 2023) such as white lupin (*Lupinus albus* L.), dwarf pigeon pea (*Cajanus cajan* (L.) Millsp.), jack bean (*Canavalia ensiformis* (L.) DC.) and *Stylosanthes* (*Stylosanthes* spp.) standing out.

Most of the species used as green manure are propagated by seeds, so the use of high-quality seeds is important for proper germination, speed, and uniformity in the formation of vigorous seedlings and establishment of the crop in the field (Alvarenga et al., 2020), allowing the full expression of its capacity to produce biomass, as well as improving physical, chemical and biological characteristics of the soil.

Seed quality can be analyzed through precise techniques that contribute to the selection of lots in the internal quality control programs of seed producing companies, which makes it possible to increase the efficiency of the production system and the use of better-quality seeds (Soares et al., 2023).

Image analysis by means of X-rays is an important technique for the identification of internal damage in seeds that, in a fast, accurate and non-destructive way, makes it possible to detect deteriorated tissues, seeds with empty spaces, mechanical damage or damage caused by insects, and well-formed seeds. Thus, it is possible to establish a direct relationship between the presence of seed damage and the occurrence of abnormalities in the respective seedlings or seed mortality, affecting the percentage of germination, for instance by mechanical damage resulting from adverse practices carried out in pre- and post-harvest, leading to ruptures in the endosperm, in the embryonic axis or in the region of nutrient translocation to the embryonic axis (Cicero et al., 1998). In the pre-harvest it is possible to identify mechanical damage and damage caused by insects in cowpea (Rego et al., 2023), and in the post-harvest, damage during the drying process in soybean (Brito et al., 2020).

The radiography technique allows seed tissues to absorb X-rays so that the extent and location of lesions in seeds are identified, with individual evaluation in expanded images (Arruda et al., 2016), and seed coat thickness, density, and composition of seed tissues are influencing factors in obtaining the images (ISTA, 2004).

In addition to detecting damage to seeds, the X-ray technique allows the measurement of empty space with the aid of dedicated computer programs, being able to provide complete information on the association between internal morphology and performance during the germination process. This procedure can complement the assessment of the physiological potential of seeds, since the presence of damage or increase in empty space within seeds is associated with a higher incidence of abnormal seedlings and non-germinated seeds (Rego et al., 2023).

Among many studies conducted on this subject, it is possible to mention the evaluation of deteriorated tissues in cowpea seeds (Rego et al., 2023), insect damage in seeds of common bean (Forti et al., 2008), soybean (Pinto et al., 2009), *Pinus pinea* (Farinha et al., 2018), cowpea (Melo et al., 2010; Rego et al., 2023), wheat (Karunataran et al., 2004; Nawroka et al., 2010), mechanical damage in maize (Cicero and Banzatto-Junior, 2003; Gomes-Junior and Cicero, 2012), sunn hemp (Arruda et al., 2016) and cowpea (Rego et al., 2023) and damage caused by microorganisms in sugar corn (Arkhipov et al., 2020).

The objective of the present study was to evaluate the efficiency of the X-ray technique in seeds of the green manures white lupin (*Lupinus albus* L.), dwarf pigeon pea (*Cajanus cajan* (L.) Millsp.), jack bean (*Canavalia ensiformis* (L.) DC.) and *Stylosanthes* (*Stylosanthes* spp.) through the characterization of internal morphological damage (mechanical, caused by stink bugs and deteriorated tissues) and its relationship with germination.

MATERIAL AND METHODS

The experiment was carried out at the Image Analysis and Seed Analysis Laboratories of the *Departamento de Produção Vegetal da Escola Superior de Agricultura ''Luiz de Queiroz'' (ESALQ), Universidade de São Paulo*, in Piracicaba, SP, Brazil. Commercial seeds were produced in the 2021/2022 season and were purchased from the company BR Seeds®.

The FAXITRON X-Ray (MX-20) MultiFocus Digital Radiography System (MDRS) was used to generate the radiographs of the seeds, which were exposed to X-ray emission using radiation intensity and exposure time established by the instrument and kept constant for all radiographs of each species, being 32 kV/9.92s, 32 kV/9.42s, 35 kV/9.62s and 28 kV/8.12s for white lupin, dwarf pigeon pea, jack bean and *Stylosanthes*, respectively.

To obtain the radiographs, two hundred seeds of each species were previously identified and fixed in cells on an acetate sheet, using transparent adhesive tape to keep the embryonic axis parallel to the plate. Based on the images obtained, the seeds were classified according to the location, intensity and type of damage present, considering class 1 as no damage, class 2 as fissures of small extension or not deep in the tissues and distant from the region of nutrient translocation to the embryonic axis (non-severe damage) and class 3 as fissures of great extension, deep or in a region close to the embryonic axis (severe damage): embryonic axis without damage (E1), embryonic axis with non-severe damage (E2), embryonic axis with severe damage (E3), cotyledons without damage (C1), cotyledons with non-severe damage (C2) and cotyledons with severe damage (C3). The types of damage were mechanical damage, insect damage, and deteriorated tissues. The identification of mechanical damage, damage caused by stink bugs and deteriorated tissues was performed through observation of the images, based on the visual analysis and intensity of the gray color in the X-ray images of the seeds, considering the shades of gray between the damaged and undamaged tissues and the ways in which the damage appeared in the seeds, compared to an image of an undamaged seed (Pinto et al., 2009).

After obtaining the radiographic images, the seeds of each previously identified species were subjected to the germination test, by means of four replications of 50 seeds arranged between germination paper (Germitest®) previously moistened with a volume of water equivalent to 2.5 times the mass of the non-hydrated paper and kept in a B.O.D. (“Biological Oxygen Demand”) germinator at 20 °C.10 days^{-1}, 25 °C.10 days^{-1}, 30 °C.8 days^{-1} and 20-30 °C.10 days^{-1}, for white lupin, dwarf pigeon pea, jack bean and *Stylosanthes*, respectively, according to the recommendations contained in the Rules for Seed Testing (Brasil, 2009).

RESULTS AND DISCUSSION

Radiographic analysis allowed visualizing the internal structures and identifying the occurrence of damage to the seeds of white lupin, dwarf pigeon pea, jack bean and *Stylosanthes*, such as damage caused by tissue deterioration, mechanical damage, and insect damage. It was also possible to associate the damage with the germination process.

The results of percentage of normal and abnormal seedlings, dead seeds and moisture content are presented in Table 1. The minimum percentage of germination required is 70%, 75% and 60% for dwarf pigeon pea, jack bean and *Stylosanthes*, respectively (Brasil, 2008) and 85% for white lupin (Almeida et al., 2015). It was observed that only the seeds of white lupin and *Stylosanthes* showed germination above the minimum for commercialization recommended by the legislation. Adverse environmental conditions or cultural practices at any stage of seed production can negatively interfere with germination performance (Choudhury and Bordolui, 2023).

Moisture content was 6.9%, 8.0%, 7.9% and 6.1% for seeds of white lupin, dwarf pigeon pea, jack bean and *Stylosanthes*, respectively. These values were considered adequate for the quality of the radiographs and visualization of the internal tissues according to each species (Table 1), since the moisture content factor influences the optical density; the lower the moisture content of the seeds, the higher the optical density, i.e., the absorption of radiation by the tissue, producing clear images that allow the differentiation of the internal structures of the seeds visualized on the radiographs (Simak, 1991). This influence was clearly proven in soybean seeds, which, when x-rayed with different moisture contents, showed differences in the tones of seeds, especially of vital structures, which allows assisting studies on seed moisture content when compared with the conventional methodology (Trujillo et al., 2021).

The relationship between the physical, physiological, and sanitary quality of white lupin seeds is shown in Figure 1. In the present study, there was no occurrence of seeds with empty spaces. Examination of the seeds showed that the most frequent damage was mechanical injury, which mainly affected the embryonic axis (Table 2). In a study with sunn hemp (*Crotalaria juncea*) seeds, damage (mechanical, by stink bugs, or by deteriorated tissue) located on the embryonic axis was closely related to the occurrence of abnormal seedlings and dead seeds (Arruda et al., 2016). A total of 13% and 22% of mechanical damage to the embryo was observed at the non-severe and severe levels, respectively, totaling 35% of the seeds evaluated, resulting in 35 abnormal seedlings and five dead seeds (Table 1). There was low occurrence of damage to the cotyledons (5 to 6%), regardless of severity. There was low occurrence of insect damage and deteriorated tissues in the cotyledons and no insect damage in the embryonic axis. These results are corroborated by the study conducted by Xueguan et al. (2016) in which X-ray images allowed the identification of mechanical damage that affected the quality of tomato seeds, causing tissue deterioration and the formation of abnormal seedlings.

In the analysis of the X-ray images, the absence of darkened spots on the seed shown in Figure 1A, especially in the embryo (highlighted by a red elliptical ring), indicates the physical integrity of this seed, in which the tissue is healthy and well formed, originating a normal seedling (Figure 1B), with the essential structures fully developed.

The relative density of the seed is related to the levels of radiolucency, which is the permeability of tissues to radiation, although with a certain resistance to this passage, of radiopacity, defined as a property of a material or substance that prevents the passage of X-rays; the radiolucency and radiopacity of a given material are translated to the image in gray values. As the seed tissues are well formed and do not show damage, the radiation from X-ray beams

Table 1. Percentage of normal and abnormal seedlings, dead seeds and moisture content (%) of a total of 200 seeds of white lupin (*Lupinus albus* L.), dwarf pigeon pea (*Cajanus cajan* (L.) Millsp.), jack bean (*Canavalia ensiformis* (L.) DC.) and *Stylosanthes* (*Stylosanthes* spp.) evaluated.

Species	Normal (%)	Abnormal (%)	Dead (%)	Moisture content (%)
White lupin	80	18	2	6.9
Dwarf pigeon pea	54	18	28	8.0
Jack bean	68	23	9	7.9
Stylosanthes	65	9	26	6.1

Table 2. Occurrence (%) of mechanical damage, insect damage and deteriorated tissues in the embryonic axis (E1, E2, E3) and cotyledons (C1, C2, C3) of white lupin (*Lupinus albus* L.) seeds.

Embryonic axis	Mechanical damage (%)	Insect damage (%)	Deteriorated tissue (%)
E1 - not observed	65	100	93
E2 - non-severe	13	0	0
E3 - severe	22	0	7
Cotyledons			
C1 - not observed	89	98	94
C2 - non-severe	5	2	4
C3 - severe	6	0	2

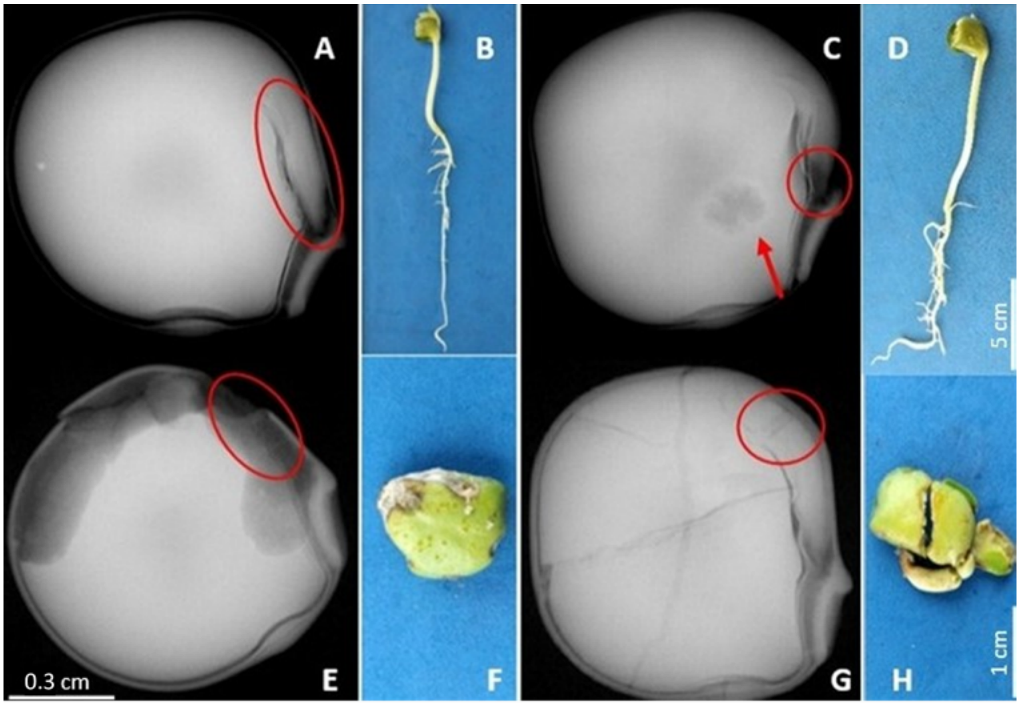

Figure 1. Radiograph of white lupin (*Lupinus albus* L.) seeds without internal damage (A), resulting in normal seedling (B); damage by stink bug in a region far from the embryonic axis (C), resulting in normal seedling (D); deteriorated tissue (E), resulting in dead seed (F); mechanical damage (G), resulting in dead seed (H).

has greater resistance to pass through the seed, forming light gray images, while deteriorated tissues are less dense and, therefore, offer less resistance to the passage of X-ray photons, generating dark images (Medeiros et al., 2018).

Considering that seed mass is associated with the number and size of cells in the tissues of the embryo, endosperm and seed coat, as well as several factors that influence the translocation of reserves during seed maturation, less dense tissues may also be a consequence of a reduced amount of reserves in these sites, such as proteins, lipids and starch and an embryonic malformation, which also contributes, in most species, to the decrease in seed germination and vigor (Ohto et al., 2018; Zhao et al., 2018; Doll et al., 2020). Thus, the mobilization of reserves is essential for seed germination and vigor, as found in *Erythrina velutina* seeds under low temperatures (Felix et al., 2020). This relationship between tissue density and germination, however, has not been established for mung beans, yopo, and rice (Machado et al., 2020; Pinheiro et al., 2022; Silva et al., 2023).

Damage caused by stink bugs, a sanitary problem that also influences physical and physiological quality, gives rise to typical circular lesions that can be deep and wrinkled, found alone or together with darkened lesions in the seed tissues (França-Neto and Kryzanowski, 2018), as indicated by an arrow in Figure 1C. However, as the observed occurrence of damage was low and in a region far from the embryonic axis, it was not possible to verify a relationship between the presence of damage and the formation of abnormal seedlings, because seeds with non-severe damage to the embryonic axis and severe damage to the cotyledon can give rise to normal seedlings (Gomes-Junior and Cicero, 2012). However, depending on the species, stink bug damage occurring even in the region opposite to the embryonic axis can result in the formation of abnormal seedlings, as seen with cowpea seeds (Rego et al., 2023).

Figure 1 also shows that the darkening of the embryo end of 1C seed, which highlights the presence of tissues with low mass density and possibly deterioration in the radicle tip region, may be due to mechanical or moisture damage, leading to the formation of an atypical root system with shortened roots, as shown in Figure 1D. In the study conducted by Pinto et al. (2009), the analysis of X-ray images also allowed the identification of damage caused by stink bugs and mechanical damage in soybean seeds from four lots, confirming the difference in the viability and vigor of the lots detected by the tetrazolium test.

The seed shown in Figure 1E has dark spots, which are characteristic of severely deteriorated tissues, occurring in the region of the embryo, preventing its differentiation, while in Figure 1G it is possible to visualize the occurrence of mechanical damage throughout the length of the seed, including the region of the embryonic axis, reaching the vascular region, the cortex and the central cylinder, which allows this seed to be classified as non-viable (Brasil, 2009). The loss of viability can be attributed to the fact that damage to this region can affect the translocation of nutrients from the cotyledon to the root or shoot, disrupting the plumule-hypocotyl-radicle axis and therefore preventing the development of any of these structures. As a result, damaged seeds can result in dead seeds or abnormal seedlings, i.e., seeds that do not germinate or do not have the essential structures for the development of a normal plant until the adult stage, as can be seen in Figures 1F and 1H. Likewise, spots on X-rayed *Moringa oleifera* Lam. seeds also led to the production of abnormal seedlings in the study conducted by Noronha et al. (2018).

The manifestation of damage in the different tissues that form the seeds and their effects on the development of the respective seedlings are associated with the occurrence of damage in seeds caused by cultural practices that occur before, during and after harvest, and may culminate in physical, genetic, biochemical and physiological changes, whose main consequence is oxidative damage caused by free radicals and reactive oxygen species, which lead to protein oxidation, lipid peroxidation, chromosomal abnormalities, and DNA damage, resulting in increased loss of seed leachate, decreased respiration rates and ATP production, loss of enzymatic activity, and structural breakdown of organelles (Choudhury and Bordolui, 2023), so the analysis of the radiographs obtained allows the association between certain symptoms present in the internal tissues of the seed and the production history of the lot.

In pigeon pea seeds, the most prominent damage was mechanical, which occurred in high frequency and severity (Table 3). This type of damage was observed mainly in the embryonic axis, constituting 57% of the seeds evaluated, of which 19% were considered to have non-severe damage and 38% were considered to have severe damage. In the cotyledons, there were 13% of non-severe mechanical damage and 23% of severe mechanical damage, totaling 36%, which led to 36 abnormal seedlings and 57 dead seeds (Table 1). No insect damage was observed, but 8.5% of non-severe deteriorated tissues occurred in the cotyledons and 7% in the embryonic axis.

Images of seeds and seedlings of pigeon pea are shown in Figure 2. Figure 2A shows a well-formed seed with healthy tissues, as it does not have darkened regions throughout its extension and the seedling originated from it (Figure 2B) has all the functional structures present and well developed. On the other hand, Figure 2C shows a typical spot of degraded tissue in the region close to the plumule, the consequence of which manifested itself as the absence of an aerial part in the seedling (Figure 2D).

Table 3. Occurrence (%) of mechanical damage, insect damage and deteriorated tissues in the embryonic axis (E1, E2, E3) and cotyledons (C1, C2, C3) of dwarf pigeon pea (*Cajanus cajan* (L.) Millsp.) seeds.

Embryonic axis	Mechanical damage (%)	Insect damage (%)	Deteriorated tissue (%)
E1 - not observed	43	100	92
E2 - non-severe	19	0	1
E3 - severe	38	0	7
Cotyledons			
C1 - not observed	64	100	80
C2 - non-severe	13	0	8
C3 - severe	23	0	12

In Figure 2E it is possible to identify fissures along the entire length of the seed, which reached the cotyledons and the embryonic axis, completely preventing the full development of the embryo, as shown in Figure 2F. Internal damage detected by radiographic images and its association with abnormal seedlings was clearly observed in seeds of pumpkin (Carvalho et al., 2009) and pearl millet (Javorski et al., 2018).

The severity of mechanical damage is based on its location, extent, and depth, because when it is severe and occurs in the cotyledons (>50% of affected tissues or in the vicinity of the embryonic axis) or in the embryonic axis, it leads to the formation of abnormal seedlings (without shoots or roots) or dead seeds (Arruda et al., 2016). When severe damage occurs to the cotyledons, it can restrict the passage of photoassimilates, reducing the availability of reserves to the embryo, in a situation where the seeds even germinate but form atypically small seedlings (Rego et al., 2023). However, the damage will always be more severe when it reaches the embryonic axis (França-Neto and Kryzanowski, 2018).

In a study with common bean (*Phaseolus vulgaris* L.) seeds, it was found that seeds that showed severe mechanical damage, both in the embryonic axis and in the cotyledons, generated abnormal seedlings in the first germination count test, which also occurred for non-severe mechanical damage, while seeds that did not show mechanical damage generated a higher percentage of normal seedlings (Forti et al., 2008).

The evaluation of jack bean seeds showed the occurrence of mechanical damage, most of which at a severe level (13%) when in the cotyledon and at a non-severe level (11%) when in the embryonic axis (Table 4). There was virtually no incidence of insect damage, with an occurrence of 1%, and there was low occurrence of deteriorated tissues in the seeds, regardless of the severity. Even with the low level of severe mechanical damage, the percentage of abnormal

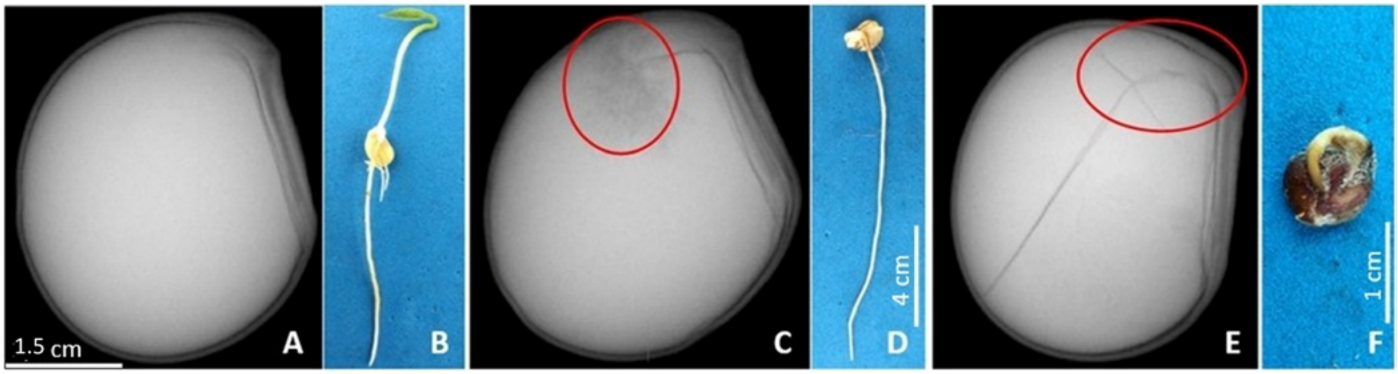

Figure 2. Radiograph of dwarf pigeon pea (*Cajanus cajan* (L.) Millsp.) seeds without internal damage (A), resulting in normal seedling (B); deteriorated tissue (C), resulting in abnormal seedling (D); mechanical damage (E), resulting in dead seed (F).

Table 4. Occurrence (%) of mechanical damage, insect damage and deteriorated tissues in the embryonic axis (E1, E2, E3) and cotyledons (C1, C2, C3) of jack bean (*Canavalia ensiformis* (L.) DC.) seeds.

Embryonic axis	Mechanical damage (%)	Insect damage (%)	Deteriorated tissue (%)
E1 - not observed	84	99	92
E2 - non-severe	11	1	3
E3 - severe	5	0	5
Cotyledons			
C1 - not observed	85	99	95
C2 - non-severe	2	1	3
C3 - severe	13	0	2

seedlings of this species was the highest (23%), indicating that this abnormality is related to another stressful factor to the seeds, which may be the presence of pathogens or inadequate environmental conditions in transport and storage, such as high temperature and relative humidity (Choudhury and Bordolui, 2023).

Images of the internal structure of jack bean seeds and seedlings are shown in Figure 3. The image in Figure 3A shows a well-formed jack bean seed with no evidence of mechanical or insect damage, unlike Figures 3C and 3E. In a study with maize seeds, it was found that seeds with longitudinal mechanical damage in the intermediate region can generate normal seedlings (Cicero and Banzatto-Junior, 2003). This phenomenon was not observed in jack bean seeds (Figures 3C and 3E) due to the greater depth of mechanical damage caused in the region of nutrient translocation to the embryonic axis, leading to the formation of abnormal seedlings (Figure 3D) and dead seeds (Figure 3F). In addition to the fissures, Figure 3E shows the dark-colored radicle end, which is a sign of deteriorated tissues, completely preventing the formation of a seedling. The damage found in higher frequency in seeds from seven cowpea lots was mechanical, which was associated with abnormal seedlings and non-germinated seeds (Rego et al., 2023), and for flaxseeds, radiographic images in association with artificial intelligence showed great accuracy in identifying this type of damage (Nadimi et al., 2023).

Stylosanthes seeds showed 15% severe damage of deteriorated tissues in the embryonic axis and 12% in the cotyledons (Table 5), with 9% of abnormal seedlings and 53% of dead seeds (Table 1). There was no insect damage and there was a low incidence of mechanical damage, especially in the cotyledons, which may be associated with the morphology of the seed, given its small dimensions and its thick and rigid coat, as reported by Chaves et al. (2017), who needed to perform scarification to intensify and accelerate imbibition and germination.

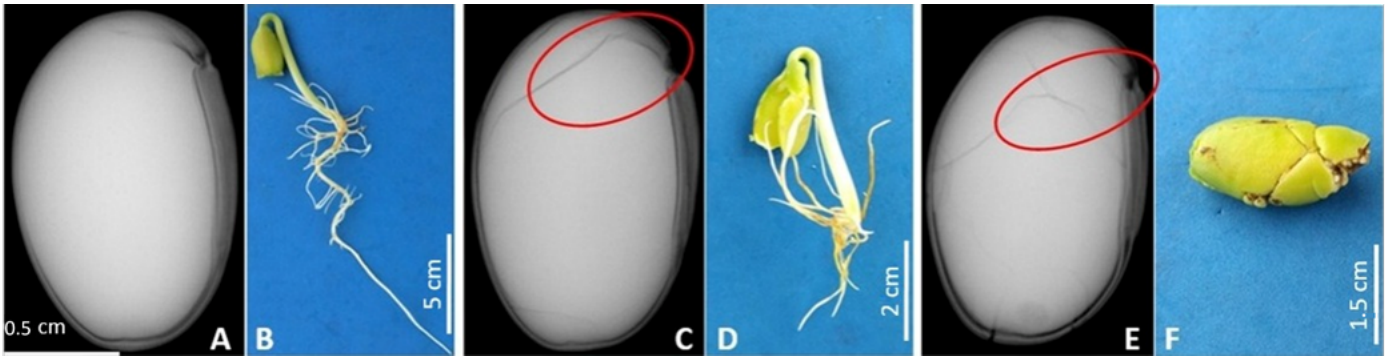

Figure 3. Radiograph of jack bean (*Canavalia ensiformis* (L.) DC.) seeds with no internal damage (A), resulting in normal seedling (B); mechanical damage (C), resulting in abnormal seedling (D); mechanical damage (E), resulting in dead seed (F).

Table 5. Occurrence (%) of mechanical damage, insect damage and deteriorated tissues in the embryonic axis (E1, E2, E3) and cotyledons (C1, C2, C3) of *Stylosanthes* (*Stylosanthes* spp.) seeds.

Embryonic axis	Mechanical damage (%)	Insect damage (%)	Deteriorated tissue (%)
E1 - not observed	92	100	79
E2 - non-severe	2	0	6
E3 - severe	6	0	15
Cotyledons			
C1 - not observed	95	100	85
C2 - non-severe	1	0	3
C3 - severe	4	0	12

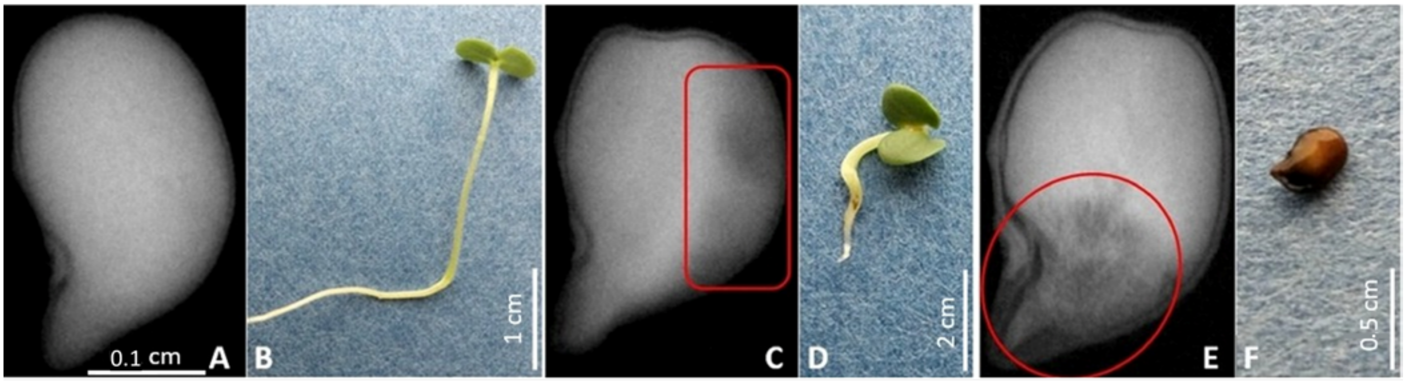

Figure 4. Radiograph of Stylosanthes (*Stylosanthes* spp.) seeds without internal damage (A), resulting in normal seedling (B); deteriorated tissue (C), resulting in abnormal seedling (D); deteriorated tissue (E), resulting in dead seed (F).

In Figure 4, the internal tissues of the seeds and the respective seedlings originated from them are exposed, and the seed of Figure 4A and its seedling are apparently well formed, unlike Figure 4C, with typical spots of deteriorating tissue in the cotyledons, in a region that may not prevent the formation of the seedling, but will provide it with a smaller amount of nutritional reserves, thus leading to the formation of a less developed seedling (Figure 4D). This result confirms what other authors have observed, i.e., not only the severity of the damage will inhibit germination, but also the site where it occurs. In Figure 4E, however, it is clear that the entire region of development of the plumule-hypocotyl-radicle axis is compromised, which culminated in seed death (Figure 4F).

Most of the damage found in the seeds of white lupin, dwarf pigeon pea, jack bean and *Stylosanthes* was mechanical, followed, to a lesser extent, by damage caused by insects, both in the embryonic axis and in the cotyledons, which caused deterioration in the tissues of different internal structures and was clearly identified by the X-ray test. These results are consistent with those observed in a study with *Crotalaria juncea*, in which there was a higher occurrence of mechanical damage (16.67%) in the embryonic axis and cotyledons, and a low occurrence of damage by stink bugs (0.67%), which may be associated with damage occurring during harvest (Arruda et al., 2016).

For the seeds of the green manures in question, it was possible to establish a direct relationship between the physical characteristics, the tissue density of the seed structures and the physiological performance.

CONCLUSIONS

Image analysis by means of the X-ray technique allows evaluating the internal morphology of seeds of white lupin (*Lupinus albus* L.), dwarf pigeon pea (*Cajanus cajan* (L.) Millsp.), jack bean (*Canavalia ensiformis* (L.) DC.) and *Stylosanthes* (*Stylosanthes* spp.), and the occurrence of damage is related to negative aspects in germination.

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