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Thermal imaging of paddy seeds for quality assessment

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Abstract
The emission of infrared radiation from objects of investigation provides a viable non-contact imaging mode through thermal imaging which is a motivation to conduct thermal imaging experiments on seeds for assessing the quality of paddy seeds. It consisted of seed collection, segregation, sample preparation, thermal imaging, and analysis besides test of germination for comparison. We collected paddy seeds from local seed distributors and segregated them into low, medium, and high-quality seeds based on their physical characteristics. Then, the seeds were kept in moistened filter paper, dried, and placed over a petri dish. Next, seeds of a particular quality in a petri dish were under irradiation of a halogen lamp for 40 seconds followed by a video recording of the emission of samples using an infrared thermal imaging camera for a period of 60 seconds. We could collect and carefully tabulate emission temperatures of the sample of each quality for every 10 seconds using the video image. Finally, the sample time-temperature plot has shown that a higher-quality seed radiates at higher temperature (39°C to 33.9°C) than low-quality seeds (36.9°C to 32.8°C). In order to compare the behavior of IR thermal emission of paddy seeds, a preliminary study of germination test was conducted which has shown that germination (%) in CO 50 seeds is higher than ADT 42 seeds and variation of seedling emergence among the seeds. In conclusion, the current research suggests that infrared thermal imaging techniques may be considered to assess the quality of the seeds, however, it requires confirmation with more experiments on various paddy samples.

Keywords: Emission, Halogen lamp, Infrared thermal imaging, Paddy seed, Seed quality, Temperature

Introduction

India's main food crop is paddy, or *Oryza sativa* (Sinha et al., 2020). Since seeds are the main input used to form crops as well as plants, farmers and seed testing stations are usually very concerned about ensuring good quality (ElMasry et al., 2020). The seed quality evaluation was the focus of major research so the benefit of increased production along with good quality agricultural produce (Kim et al., 2013). The ability of seedlings and grain yield are directly impacted by the vigor of rice seeds (Jin et al., 2022). Seeds possess various bio components such as fatty acids, tocopherols, tocotrienols, phytosterols, and different triacylglycerols which are related to the seed's quality (Mota et al., 2021). Research has revealed that seed vigor gradually declines following harvest and storage. Agriculture yields are directly impacted by low-vigor seeds' constant decreased probability of germinating (Gebeyehu, 2020). Inspectors are not able to identify paddy seeds that are of the highest, middle, or lowest

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quality during seed purity tests. Expert examiners assess purity by looking at the paddy's appearance, form, and color. Manual separation of seeds through visual examination is physically intensive and consumes more time (Jamil and Bejo, 2014). The ISTA (International Seed Testing Association) offered guidelines on germination tests, immunoassay tests, conductivity tests (Rahman and Cho, 2016), tetrazolium stains (Hosomi et al., 2011; Merritt et al., 2014; and Olesen et al., 2015), that are many of the traditional methods used to test the viability of seeds. They are, nevertheless, laborious, damaging, and time-consuming tasks that are more prone to human error. Traditional methods cannot meet the high standards for accurate and non-invasive seed vigor identification required by modern agriculture (Liu et al., 2020).

The non-destructive seed grading system development that utilizes computer vision techniques as well as image processing has drawn significant attention from researchers across multiple fields (Uddin et al., 2021; Liu et al., 2020; Kiratiratanapruk et al., 2020; Galletti et al., 2020; Barbedo et al., 2018; Matousek et al., 2016; Shrestha et al., 2016; Gong et al., 2015; Mahesh et al., 2015; Zareiforoush et al., 2015). By detecting the infrared radiation, a body surface emits, thermal imaging is a non-contact", non-destructive approach to compute temperature (Arora et al., 2008). The electromagnetic spectrum includes infrared rays, which have wavelengths in between visible light and radio waves. Infrared radiation has a wavelength of 700 nm to 1 mm. According to Schulz and Baranska (2007), any object that emits infrared radiation in the electromagnetic spectrum at a temperature greater than absolute 0 (- 459 °C or 0 K or 273.15 °C) will produce a unique spectrum that will reveal the identity of the object. Thus, it is possible to identify and assess an object's thermal state by analyzing the infrared spectrum it emits (Satish Kumar et al., 2018).

To determine the association among the emission temperature data and seed quality, we used an infrared thermal camera to record thermal images of paddy seeds of varying quality and to track the emission temperature of various varieties of paddy seeds. Therefore, our study investigates a physical method that is non-intrusive and can quickly and accurately evaluate "seeds".

Materials and Methods

Seed certification standards, a brief overview of seed quality parameters, seed collection and Thermal Imaging of seeds have been provided in the following section.

A. Seed Certification Standard

Seed Certification Standards of agricultural crops around twenty items like Cereals (paddy - *Oryza sativa* L, wheat, etc.), millet, forage crop (rice-bean, guinea grass, etc.), Tissue Culture Raised Propagule (banana, potato etc. with their tissue culture standard) including green manure are listed that mentions the factors of paddy seed standard for pure seed (minimum 98%), moisture (maximum 13%), Germination (minimum 80%) besides others.

Genetic and physiological characteristics are related to seed quality. Genetic component involves differences between two or more genetic lines (Trivedi and Gunasekaran, 2013).

B. Seed Quality Parameters

The section outlines the tests of physical purity, moisture content, germination and vigor besides speculative relationship between the traditional seed parameters and the characteristics of thermal imaging.

Tests concerned to varietal purity, weed and other crop seed, inert material, other varieties, moisture content, germination and vigor. The true seeds of the variety based on size, seed shape, absence of weed, other seeds and inert matter. Color also associated with quality since discolored seeds highly affect seed quality (Praveen et al., 2022) whereas the genetic purity of seeds may be detected by identification of various molecules, finger printing of isotope, analysis of mineral elements besides DNA analysis.

Some amount of water would be present in the seed called as moisture content that can be calculated using mass of the seed before and after drying. In germination and vigor test, where germination corresponds to the emergence of seedling and vigor relates with time taken for seedling and afterwards.To perform seed germination test, a seed compartment having 100 / 50 / 25 seeds with their replicates of 4 / 8/ 16 would fulfill the requirement of a minimum of 400 seeds that has been recommended by ISTA under optimum conditions of moisture, temperature with pre-treatment to the seed for eliminating some degree of dormancy and first count to final count have to be made from 5^{th} day to 14^{th} day of planting. Evaluation of germination test also supports to achieve classifying the seeds into dead seeds, normal seedlings, abnormal seedlings, ungerminated and hard seeds (Rajendra Prasad, 2023).

Test results of seed are given as in percentage for purity, germination, speed of germination and viable. In addition, vigor indices are calculated using germination (%), mean seedling length and mean seedling dry weight etc. Definitions and the details of aforesaid parameters are given elsewhere (Trivedi and Gunasekaran, 2013; Rajendra Prasad, 2023). Meanwhile, automated measurements of these test results are in progress (Durai, et al., 2018; Zhang et al., 2023).

The physical and physiological qualities of samples were taken into account in the following manner.

Few samples for thermal imaging test were selected by visual examination. And moisture removal of the samples has been accomplished by drying the seeds in hot sun. While using large number of samples, weight of the seeds and images of the seeds can be used to determine pure seed.

Regarding germination test on the two varieties viz. CO 50 and ADT 42 that were taken for investigation. The test was conducted adhering ISTA rules and standards as stated in Seed Technology of Tamilnadu Agricultural University Agritech Portal (TNAU-2014) which recommended petriplate method i.e. keeping paddy seeds in between two moist filter paper in a petridish and observed seeds growth (Chiranjeevi et al., 2021). Fig. 1 illustrates the steps involved in the test of germination. To perform the test, sixteen seeds were randomly chosen from the heaps of ADT 42 and CO 50 varieties (Fig. 1a) in two different petridish as two samples (Fig. 1b). The germination (%) of CO 50 and ADT 42 (Fig. 1c) were calculated and the values are 56% and 25% respectively during the first count i.e. on 5^{th} day from the start day of germination event.

C. Seed collection

A paddy seed distributor situated in Thanjavur, Tamil Nadu, India offered Paddy seedsof two various types (ADT 42, and CO-50). Based on physical characteristics such as size, color, mass, etc., three different categories of each seed variety i.e. low, medium, and high-quality seeds were segregated. Then, three categories of samples from each variety were used in thermal imaging experiments. Initially, the seeds have been placed in Petri dishes, covered with damp filter paper, and left undisturbed for eight hours to ensure complete imbibition.

D. Thermal imaging of seeds

An infrared thermal imager (FLIR T 540 Thermal Imaging Camera, with thermal sensitivity of 0.03°C, resolution of 464 x 348 pixels, and frame rate of 30Hz), a halogen lamp (500W; 240V), and a computer for tracking temperature data make up the thermal imaging system developed in this study (Liu et al., 2020). Figure 2 depicts the experimental setup.

The samples of seed are kept on filter paper and blotted dry before being subjected to thermal imaging. Following 40 seconds of exposure to an irradiation pulse via a convex lens from a halogen lamp, the lamp is switched off. This type of irradiation does not harm seeds. Samples are allowed to cool to room temperature after the cooling process, and in this setup, thermal videos are observed for 60 seconds. At one meter from the sample, the thermal camera recorded images in — real-time at a frame rate of 30Hz. We examined the pictures that we took out of the thermal imager's video report between 0 and 60 seconds. To obtain thermal images for CO 50 and ADT 42 paddy seeds, the aforesaid process has been employed and fig. 3 displays the thermal images of the paddy seeds.

Results and Discussion

Mainly seed quality depends on the ability of germination of seed, the germination test was carried out in order to compare the germinating event with the findings of thermal imaging studies. Fig. 1a-c depicts the steps of germination test. Since the objective of the investigation is on examining the variation of germination emergence in the two samples, a sample is limited to a total of 16 seeds only rather 400 seeds as suggested by ISTA guidelines. Fig. 1b shows the seed variety in a petri dish at start day. Fig. 1C brings the intra (among the seeds of a particular variety) and inter (between the seed varieties) differences among radicle developments of seedling emergence event at fifth day of germination process.

The germination test on the two samples displays intra and inter differences in seedling emergence of germination event among the seeds of a variety and between the varieties of CO 50 and ADT 42 that was shown in figure 1C. Notably, the calculated germination (%) including vigor have been approximately twice in CO 50 compared to ADT 42 as evidenced from figure 1C.

Next on IR thermal emission behavior of paddy seeds, Stefan-Boltzmann law, a thermodynamics law that explains emission of radiant energy of the real objects. It states that the emission energy E =

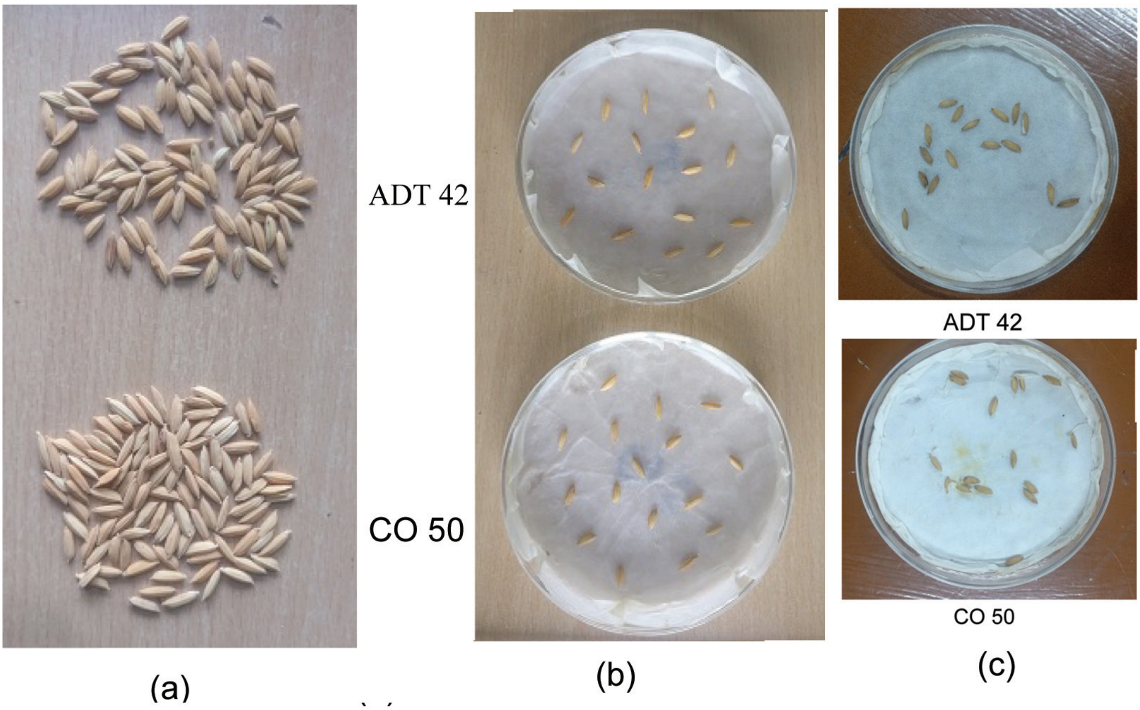

Figure 1. Steps of Germination Test, (a) Seed varieties (ADT 42 and CO 50) heap, (b) Sample containing 16 seeds in two petriplates at start day of germination, (c) Seedling emergence in each sample at fifth day of germination.

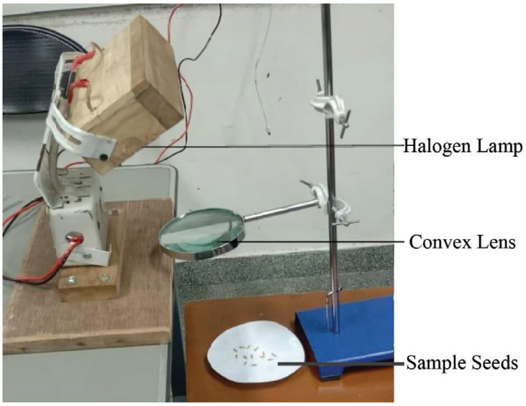

Figure 2. Convex lens, sample seeds, and a Halogen lamp make up the experimental setup.

esat[4] where 'e' is emissivity and it is 1 for perfectly black body and other objects emissivity value is less than 1, and for paddy the emissivity value is around 0.6 from 20°C to 70°C (Arslanbay and Kocabiyik, 2018) that varies depending on the nature of seed. In the case of thermal imaging, emitted radiant energy from the surface of the test specimen is captured over certain time duration and is analyzed for observing presence of fingerprints of the internal characteristics of the specimen. For practical applications, it is tedious to capture and monitor the weak signals with very small differences due to their emissivity variations which is called passive imaging system. Instead, a method based on the weak signals of spontaneous emission, the test object is subjected to external stimuli (Gowen et al., 2010) and as a response, after the stimuli is turned off, the test object would give rise of their absorbed electromagnetic energy as IR thermal signals with sufficient strength which would emerge over a period of time that depends upon the nature of the motif composition of the test object which is called as active thermal imaging system. Availing aforesaid phenomenon, the seeds were irradiated with halogen lamp over a period of around 40 seconds. After turning off the lamp, emanating thermal signals over the seed surface is recorded in the form of images to explore the hidden information of them for finding signature related to quality aspects of the seed (Elmasry et al., 2020).

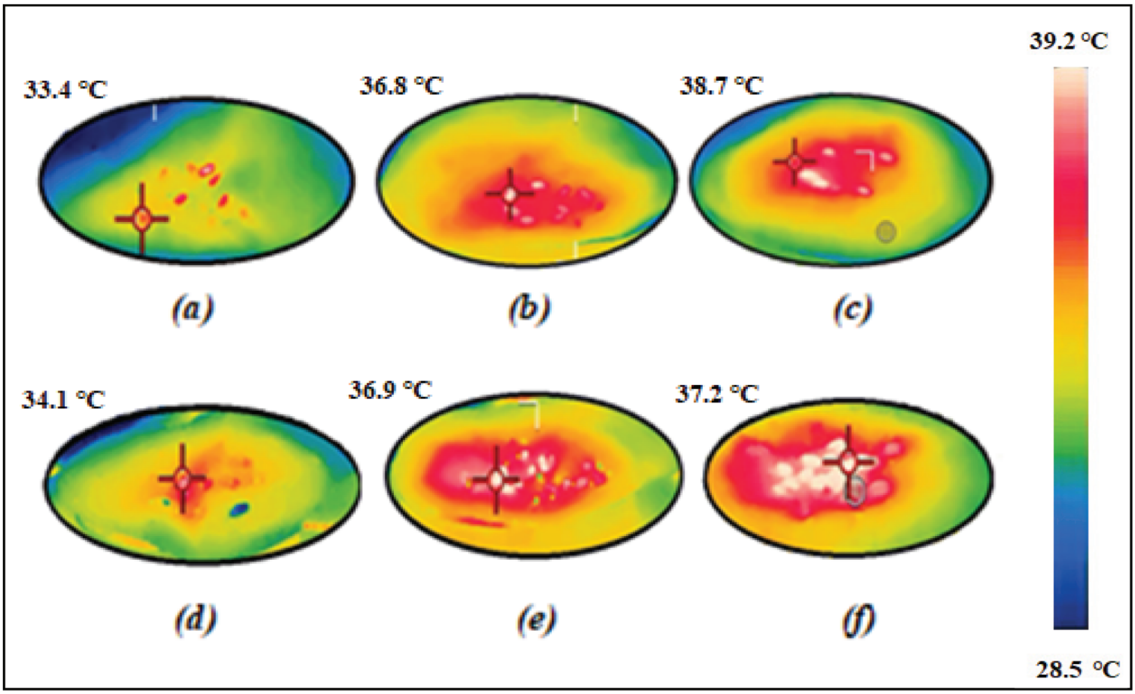

Figure 3. Thermal images of the Paddy seeds [ADT-42 paddy seeds a-poor (lower) quality, b-moderate (medium) quality, c-good (high) quality; CO-50 paddy seeds d-poor (lower) quality, e-moderate (medium) quality, f-good (Higher) quality]

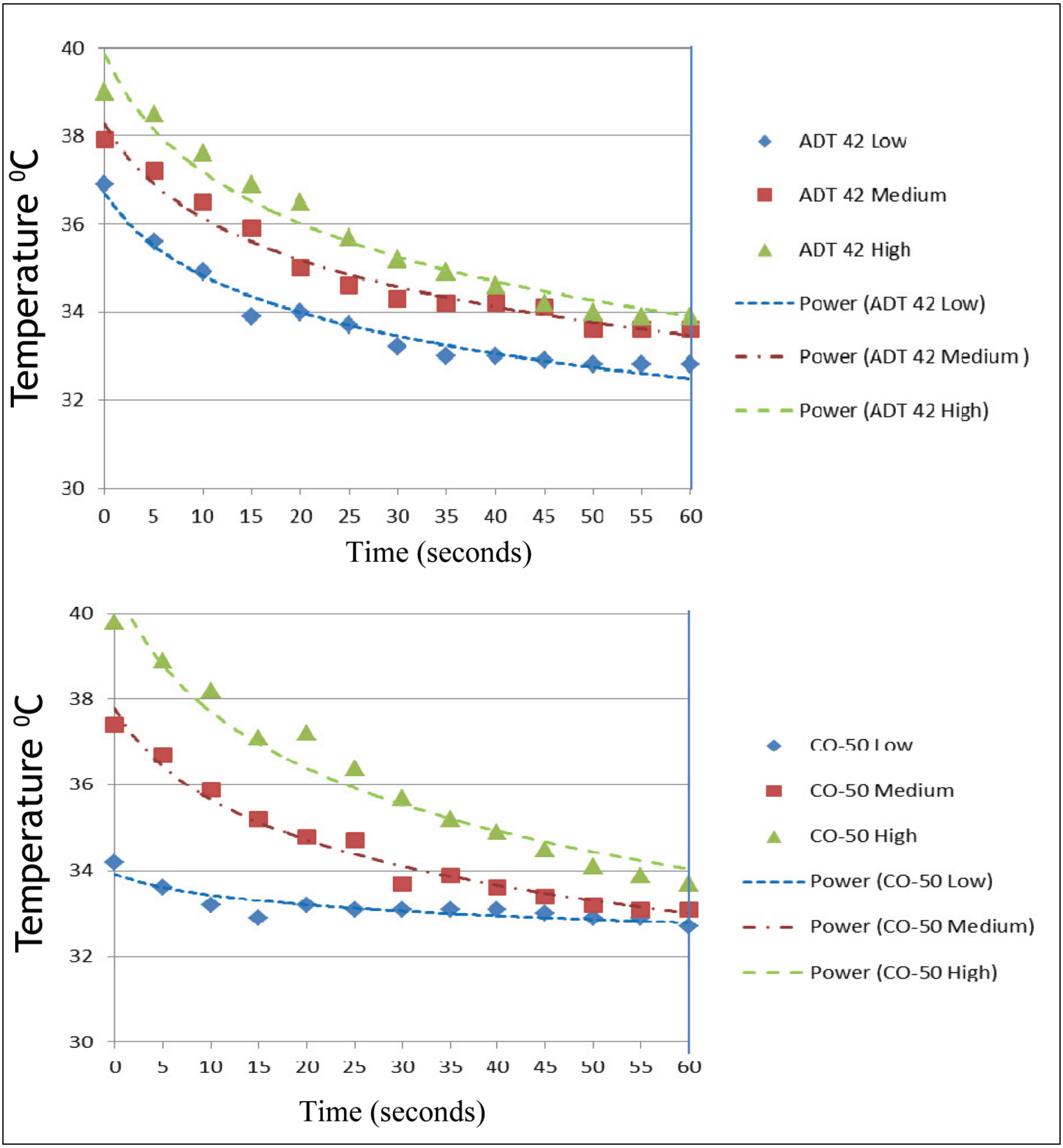

Figure 4: Thermal decay curves of paddy seeds, ADT-42, and CO-50 with fitting function $y = T_{max-}\, x^{-\acute{a}}$

After being exposed to halogen light for 40 seconds, the temperature of the ADT-42 low, medium, and high-quality seeds is 36.9°C, 37.9°C, and 39°C, respectively. After 60 seconds of thermal decay, their temperature dropped sharply to 32.8°C, 33.6°C, and 33.9°C. Like this, after 40 seconds of exposure to a halogen lamp, the temperature of CO-50 seeds of low, medium, and high quality is 34.2°C, 37.4°C, and 39.8°C. After 60 seconds of thermal decay, their temperature dropped sharply to 32.7°C, 33.1°C, and 33.7°C.

Fig. 4 displays the plots of temperature against decay time, while Table 1 provides the seed's temperature at the time of thermal decay at regular intervals.

Table 1. Temperature of the seeds at a regular time interval during thermal decay

Time(sec)	ADT-42			CO-50		
	Low(°C)	Medium(°C)	High(°C)	Low(°C)	Medium(°C)	High(°C)
0	36.9	37.9	39	34.2	37.4	39.8
5	35.6	37.2	38.5	33.6	36.7	38.9
10	34.9	36.5	37.6	33.2	35.9	38.2
15	33.9	35.9	36.9	32.9	35.2	37.1
20	34	35	36.5	33.2	34.8	37.2
25	33.7	34.6	35.7	33.1	34.7	36.4
30	33.2	34.3	35.2	33.1	33.7	35.7
35	33	34.2	34.9	33.1	33.9	35.2
40	33	34.2	34.6	33.1	33.6	34.9
45	32.9	34.1	34.2	33	33.4	34.5
50	32.8	33.6	34	32.9	33.2	34.1
55	32.8	33.6	33.9	32.9	33.1	33.9
60	32.8	33.6	33.9	32.7	33.1	33.7

When compared to ADT-42 paddy seeds, the CO-50 variety exhibits high-temperature radiation during thermal decay. ADT-42/CO-50 high-quality seeds radiate at a higher temperature (39 / 39.8 °C to 33.9 /33.7 °C) during thermal decay than low-quality seeds (36.9 / 34.2 °C to 32.8 / 32.7 °C), according to the graph. As similar to thermal imaging, the germination test on the two samples displayed the differences of seedling emergence during germination event among the seeds and between the varieties of CO 50 and ADT 42 paddy seeds. Notably, the calculated germination (%) including vigor have been approximately twice in CO 50 compared to ADT 42 as obvious in fig. 1C.

In an earlier study, thermal profile i.e., average surface temperature, thermal index values of thermal images, mean pixel value, etc. were calculated for paddy seeds to relate with their maturity stages and other properties including chaff pieces (Bejo-Khairunniza et al., 2016). The results indicated that the determined values are higher for matured seeds than chaff pieces. As image pixel intensity values and corresponding thermal values of these thermal imaging experiments are similar as above, it has been proposed to quantify the quality of seeds through the index of thermal decay constant. However, we need to conduct more experiments in combination with AI & ML techniques to classify the seeds (Jin et al., 2022; Kiratiratanapruk et al., 2020) to correctly predict the seed category in a wide range that may spread over the scale from 0 to 10 where 0 indicates dead seed and 10 indicates the highest quality.

While thermal decay of paddy seeds, there are mainly two entities that play a significant role which is the maximum temperature attained by the seed followed by their decay. It is obvious that the maximum temperature and decay process could be naturally associated with the physical and bio-chemical nature of the paddy seed which influenced the entities. Hence, the choice of Power law could accommodate well of these two entities i.e. one as a scaling constant (maximum temperature) and the other one as exponent (decay constant) to time with high R^2 value around 9. Thus, the proposed 'power law regression model' may be adopted to explain the thermal decay process of paddy sample to classify paddy seeds of varying qualities.

Table 2. The value of fitting parameters for the plots of Time versus Temperature of Paddy seeds ADT-42 and CO-50.

Fitting Parameters	ADT – 42			CO - 50		
	Low	Medium	High	Low	Medium	High
T_{max}	36.692	38.264	39.848	33.92	37.786	40.712
á	0.048	0.052	0.063	0.013	0.053	0.07
R^2	0.9715	0.972	0.961	0.7933	0.9765	0.9526

In this study, the thermal decay curves were fitted by the fitting function using power law equation.

$y = T_{max-} x^{-á}$

where, T_{max} - is the maximum temperature, á - thermal decay constant and R^2 is the coefficient of determination. The fitting parameter values are tabulated in Table 2. It is noticed from the above equation that the regression fitted value of the exponent that is supposed to correspond with the thermal decay constant which seems to be high in these experiments for high-quality seeds.

Biotechnique procedures such as Chromatography-based seed analysis can provide information about the seed's profile, and analytical characterization can provide additional details to link all aspects of the seed's quality (Mota et al., 2021). In addition to the direct assessment method, the complexity of determining seed vigor can be resolved by using deep learning techniques to analyze thermal images (Jin et al., 2022).

Nevertheless, two paddy seed varieties of different categories are examined via thermal imaging method, the range of values of seed quality parameters on different categories of paddy seeds are reported by researchers for their various reasons that would contribute to work out the new / altered experiments related to seed quality in an effective manner including validation of present thermal imaging.

First, in a report of Rural Agricultural Work Experience programme for dissemination of awareness among the farmers about the methods to raise paddy seeds of good quality, they determined seed quality parameters on farm saved paddy seed samples of around twenty numbers that were collected from the selected villages of Thanjavur district delta regions of Tamilnadu. It was found that the physiological parameters of farm saved seed named Karuppukavuni Burma has shown the highest germination (%) and vigor index I with the values of 81%, and 1486 where as Mapillai samba of Surakottai village has shown the highest vigor index II with the value of 759, but moderate germination (%) i.e. 66% (Selvamani et al 2021).

In another report, the better seed quality produced under System of Rice intensification (SRI) scheme was attributed to higher test weight values that possess higher seed vigour index I and II compared to conventional transplanting methods of cultivation. The different varieties of paddy seeds also have shown significant differences in their Length/Breadth ratio among all the varieties. Based on the L/B ratio, the collected rice varieties were classified into different categories such as Tulasi (long slender), Ravi (medium slender), Varadhan (short bold), Jaya (long bold), Dhanrasi (short bold). However, the grain L/B ratio was higher around 0.01-0.02 in SRI than CT, but very few varies from 0.03 to 0.16. The Higher SRI compare to CT was attributed to better grain filling in SRI. Among the varieties studied, amylose content and alkali spreading value was significantly higher ranged from 19.25 - 26.90% and grouped under near low and intermediate to high. Overall, the mean parameters of fifteen varieties (Tulasi, Varadhan, DRRH3. etc.) viz. germination (%), Vigor Index I, and Vigor Index II of paddy under System of Rice Intensification and conventional traits were calculated as 95.58%, 3005.82 & 15430.22 and 94.33%, 2698.06 & 14,636.44 respectively. The study revealed that seed and grain quality parameters were higher in SRI method of cultivation compared to conventional transplanting (CT) (Kumar et al 2017).

A third study was on various rice varieties including CO 50 and ADT 42 which was conducted in a completely randomized design that assessed seed vigor in terms of time for radicle emergence, mean germination time, germination percentage, emergence speed, length of shoot and root, days to first and final count, vigour index –I, vigour Index –II, electrical conductivity, and field emergence.

The third study was made to categorize the twelve paddy varieties into high seed vigor based on their parameters viz. mean germination time: 32.4 to 33.1 hours, germination (%): 96-98, Vigor Index I: 3293-3410, Vigor Index II: 2414-2607 that included ADT 51, CO52 etc. whereas these aforesaid parameters are lower in ADT 42 and CO 50 and their values are 33.7, 94%, 3111, 2118 and 33.8, 94%, 3027, 1990 respectively (Vakeswaran 2023).

These variation of seed vigor index among the different varieties lead to classify the rice varieties into three groups in which ADT 42 and CO 50 were in different groups. The present thermal imaging experiments have shown distinct differences in thermal decay pattern between ADT 42 and CO 50 which can be noticed as the differences of the seedling emergence among the seeds in germination test that suggested to consider thermal decay pattern of IR imaging for seed quality assessment.

Conclusion

Two varieties of paddy seeds were gathered, and each variety's paddy seeds were divided into three quality categories. These seeds were captured in the thermal spectrum, and the temperature information was examined. In conclusion, using thermal decay constant and emission temperatures, an experimental study using thermal imaging on paddy seeds revealed variations in seed quality. However, deep learning techniques using thermal images, seed analytical characterization, and thermal imaging of seeds under various conditions could also potentially reveal the profile of seed quality.

Chromatographic methods of seed analysis can yield the profile of the seed; further information related to the physical and bio chemical properties of the seed's quality can be obtained through analytical characterization.

Finally, performing thermal imaging experiments using the paddy seeds with known seed quality parameters related to their analytical tests, genotyping, DNA extraction, etc. which may be availed from specifically the International Rice Genebank (more than 132,000 available accessions) of International Rice Research Institute (IRRI) would facilitate to examine the relationship between the existing parameters and thermal decay that may strengthen the emerging IR thermal imaging modality.

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