BIOSCIENCE JOURNAL

EVALUATION OF THE PHYSIOLOGICAL POTENTIAL OF *Panicum maximum* SEEDS BY MULTIVARIATE ANALYSIS

Francisco Elder Carlos Bezerra PEREIRA[1], Tatiane Sanches JEROMINI[2], Givanildo Zildo da SILVA[3], Salvador Barros TORRES[4], Cibele Chalita MARTINS[5]

[1] Agricultural Engineer at Pastotech, Tupaciguara, Minas Gerais, Brazil.
[2] Seed Analyst at BASF, Trindade, Goiás, Brazil.
[3] Federal University of Goiás, Jataí, Goiás, Brazil.
[4] Federal Rural University of the Semi-Arid, Mossoró, Rio Grande do Norte, Brazil.
[5] Departament of Crop Production, São Paulo State University “Júlio de Mesquita Filho”, Jaboticabal, São Paulo, Brazil.

Corresponding author:
Francisco Elder Carlos Bezerra Pereira
Email: eldercarlos12@gmail.com

How to cite: PEREIRA, F.E.C.B., et al. Evaluation of the physiological potential of *Panicum maximum* seeds by multivariate analysis. *Bioscience Journal*. 2022, **38**, e38017. https://doi.org/10.14393/BJ-v38n0a2022-53754

Abstract
The aim of this work was to identify efficient vigor tests for differentiating the seed lots, forecasting seedling emergence in the field and assessing the physiological quality of *Panicum maximum* seeds. 12 seed lots from the cultivar Tanzania and 11 seed lots from the cultivar Massai were evaluated for water content, germination, first count and germination speed index, emergence and first emergence count of seedlings in sand, root length and shoot length, analysis of SVIS® images (seedling length, vigor and uniformity index) and seedling emergence in the field. The work was conducted in a completely randomized design for tests performed in the laboratory and in randomized blocks for tests in the field. The data were subjected to analysis of variance and the means compared by Scott Knott's test at 5% probability and statistical multivariate clustering analysis and principal components analysis. The shoot and root length tests are efficient for the evaluation of the physiological potential of *P. maximum* cv. Massai, while the seedling length, vigor index and growth uniformity index tests using image analysis, seedling emergence in sand and first seedling emergence count in sand are efficient in assessing the physiological potential of seeds of *P. maximum* cv. Tanzania, and providing information similar to that of seedling emergence in the field.

Keywords: Image Analysis. Massai Grass. Multivariate Statistics. SVIS®. Tanzania Grass.

1. Introduction

Panicum maximum (Jacq.) Has been used for pastures in tropical regions of Brazil due to its capacity for dry matter production, vigorous tillers, ease of establishment, forage quality, animal acceptability and drought tolerance (Mendonça et al. 2014; Dutra et al. 2015). These attributes have led to a demand for quality seeds of this species.

Given the importance of the species, the use of good quality seeds is an essential factor in the establishment of pastures. The demands of the consumer market and the need for certification of forage seeds have encouraged seed companies to improve their quality (Melo et al. 2016; Silva et al. 2017).

The seed quality evaluation is usually carried out through germination tests and to complement the information obtained, vigor tests are also carried out (Marcos-Filho 2016). In general, several vigor tests are applied, based on performance characteristics of seeds and seedlings (Silva et al. 2017).

Among the existing vigor tests, the use of computerized image analysis is a promising alternative for the seed industry, as well as for analysis laboratories, helping in decision making (Gomes Júnior et al. 2012; Jeromini et al. 2019). In addition to indicating the physiological potential of seed lots, it will enable the reduction of risks and losses in the seed production sector (Marcos-Filho et al. 2009; Souza et al. 2014; Jeromini et al. 2019).

The quality of a seed lot is not directly measurable, since it is not calculated based on only one characteristic, as only one attribute of quality would be insufficient to differentiate the seed lots. Thus, it is necessary to use multivariate techniques such as cluster analysis and principal components (Johnson and Wichern 2005).

Multivariate statistics aims to reduce, represent, analyze, and interpret data by which several variable responses are evaluated. The multivariate data analysis methods allow a complete study of these variables, showing the links, similarities, or differences between them, with minimal possible loss of information (Hair et al. 2009), considering the importance of each variable in the existing total variation. This technique has already been successfully used for soybean (Barbosa et al. 2013), rice (Lorentz and Nunes 2013), *Brachiaria brizantha* cv. Piatã (Silva et al. 2017) and guinea grass (Pereira et al. 2020) seeds.

Research on the improvement of vigor tests for *P. maximum* seeds still needs to be further explored, and therefore, there is a current demand in the area of production and technology of forage grass seeds. Thus, the objective was to identify efficient vigor tests for differentiating the seed lots, forecasting seedling emergence in the field, and evaluating the physiological quality of *P. maximum* seeds.

2. Material and Methods

In this study, 11 and 12 commercial seed lots of *P. maximum* cvs. Massai and Tanzania, respectively, were evaluated and mechanically harvested by sweeping the soil in different production fields (Table 1).

Table 1. Origin of the seed lots of *Panicum maximum* cvs Massai and Tanzania.

Lots	Origin
	Cultivar Massai
1, 2, 3, 4, 6, 8 and 9	Auriflama – SP (20°41′08″S 50°33′17″W)
5	Guzolândia – SP (20°38′59″S 50°39′43″W)
7	Água Boa – MT (14°03′00″S 52°09′32″W)
10	Quirinópolis – GO (18°26′53″S 50°26′47″W)
11	Mesópolis – SP (19°57′58″S 50°38′17″W)
	Cultivar Tanzânia
1, 2 and 3	Guzolândia – SP (20°38′59″S 50°39′43″W)
4, 9, 10, 11 and 12	Dolcinópolis-SP (20°7′23″S 50°30′48″W)
5	Jales – SP (20°16′08″S 50°32′45″W)
6 and 7	Auriflama – SP (20°41′08″S 50°33′17″W)

The seed lots were packed in unified paper packaging and sent to the Seed Analysis Laboratory of the Plant Production Department belonging to the Faculty of Agricultural and Veterinary Sciences of the Jaboticabal Campus (Unesp). In the laboratory, they were stored in a cold chamber (9 ºC ± 2 ºC and RH 45% ± 5%) to avoid loss of quality during the experimental period (Carvalho and Nakagawa 2012). The evaluation of the physiological quality of each seed lot was carried out through the following analyzes.

Water content: two subsamples of 2.0 g of seeds were used per lot, in an oven at 105º C ± 3º C for 24 hours (Brasil 2009). The results were expressed as a percentage (wet basis).

Germination test: performed with four subsamples of 100 seeds distributed on two sheets of blotting paper moistened with an amount of water equivalent to 2.5 times the dry mass of the paper that were arranged in transparent plastic boxes (11.0 x 11.0 x 3.5 cm), at 20-30° C with a photoperiod of eight hours, and with counts performed up to 28 days (Brasil 2009). At the end of the period, normal seedlings were counted with the results expressed as a percentage (Brasil 2009).

First germination count: determined in conjunction with the germination count test performed on the third day after installation and with the results expressed as a percentage of normal seedlings (Tomaz et al. 2015).

Germination speed index: determined by a daily count of the germinated seedlings in the germination test from the third to the twenty-eighth day after sowing and calculated according to the formula proposed by Maguire (1962).

Seedling emergence in sand: sowing was carried out in washed and sterilized sand at 120° C for 120 minutes, placed in plastic boxes (30.2 x 20.8 x 6.3 cm) and moistened with 60% of the retention (Brasil 2009). Four subsamples of 50 seeds were sown at a depth of 1cm, kept in a laboratory environment (26° C ± 3° C and UR 70% ± 10%) for 30 days, when the count of the emerged seedlings was performed. The results were expressed as a percentage (Silva et al. 2017).

First emergence count: performed together with the emergence of seedlings in sand and calculating the percentage of seedlings that had emerged on the fifth day after sowing (Melo et al. 2016).

Root and shoot lengths: done with four subsamples of 10 seeds sown in a paper towel roll moistened with 2.5 times its dry mass and kept at 25°C. On the tenth day after the test was setup, normal seedlings were measured from the crown to the end of the root and from the crown to the top of the seedling plumule, with the aid of a ruler graduated in millimeters and the results expressed in centimeters per seedling (Oliveira et al. 2014).

Seedling emergence in the field: carried out with four replications of 50 seeds for each seed lot, sown at a depth of 1cm, in 1.0m long furrows spaced 0.3m apart. The count of emerged seedlings was performed on the thirty-fifth day after sowing and the results expressed as a percentage (Melo et al. 2016). During the test period, the maximum and minimum daily mean temperatures of the field environment were 31º C ± 3º C and 18º C ± 3 ºC, respectively.

Computerized analysis of seedlings: eight repetitions of 25 seeds were sown on paper towels moistened with an amount of water equivalent to 2.5 times the dry mass of the paper and kept at 25ºC for seven days. The largest seedling found in the test was identified and measured. It was 15.24 cm in length from the root end to the apex of the plumule, this being the value used to adjust the software in the evaluation of growth, uniformity and vigor indexes. For this, all seedlings were transferred to a sheet of black colored cardboard and the images were captured using a scanner (model HP Scanjet 2004), installed inverted inside a 60cm x 50cm x 12cm aluminum box, being operated through the Photosmart software, with a resolution of 300 dpi. Seedlings were analyzed using SVIS® (Seed Vigor Image System) software installed on a Pentium IV computer, 2.0 GHz CPU, 768 MB RAM and 40 Gb HD and the parameters vigor index (IV), growth index (CI), uniformity index (UI) and seedling length index (CP) were generated as described by Hoffmaster et al. (2003).

To calculate seed vigor indexes between 0 and 1000, the software was adjusted to 70:30, which corresponds to 70% of the growth index value added to 30% of the uniformity index value, following the procedure adopted by Hoffmaster et al. (2003). Seedling length data were provided by the program in pixels, which after transformation was transformed into cm, considering that one pixel corresponds to 0.02645 cm.

As for the statistical analysis for the physiological quality of the seed lots, the experiment was evaluated for each seed lot individually, using a completely randomized design with four replications. For tests carried out in the laboratory and for seedling emergence in the field, a randomized block design with four replications was used. For the tests evaluated using SVIS®, a completely randomized design with eight replications was used. The data for each test were previously tested for normality by the Shapiro-Wilk test and homoscedasticity by the Cochran test.

The data were analyzed for each parameter separately through analysis of variance and the treatment means were compared by the Scott-Knott test, at 5% probability.

Multivariate analyzes were performed after standardization of the variables in which each had a mean of 0 and a variance of 1. The analysis using the hierarchical method was calculated based on the Euclidean distance between the lots for the set of eleven variables and using Ward's algorithm for obtaining the groupings of similar lots (Sneath and Sokal 1973).

The principal component analysis was based on Ward's groups (Hair et al. 2005). Thus, the initial set of eleven variables started to be characterized by two new latent variables, which made it possible to locate them in two-dimensional figures. The adequacy of this analysis is verified by the amount of total information of the original variables retained by the principal components that show eigenvalues greater than the unit (Kaiser 1958). All multivariate analyzes were processed using the STATISTICA software version 7.0.

3. Results and Discussion

The water content of Massai seed lots varied from 8.0% to 10.3%. While in the cultivar Tanzania they were between 8.7% and 10.4%. This similarity of values was essential so that the tests for assessing the physiological quality of seeds were not affected by differences in metabolic activity, speed of moistening and deterioration due to discrepancies in these values (Tomaz et al. 2015).

The seedling emergence test in the field, used as a reference in vigor testing (Melo et al. 2017; Oliveira et al. 2017; Silva et al. 2017; Pereira et al. 2020), classified the seed lots in two vigor classes: high (lots 1 to 8) and low (lots 9 to 11) for cultivar Massai and high (lots 1 to 3), medium (lots 4 to 7) and low (8 to 12) for cultivar Tanzania (Table 2).

Table 2. Seedling emergence in the field (EF), germination (G), first germination count (FCG), germination speed index (GSI), seedling emergence in sand (ES), first seedling emergence count in sand (FCE), shoot length (SHL), root length (RTL), image analysis of seedling length (SDL), vigor index (VI) and uniformity index (UI) of 11 seed lots of *Panicum maximum*, cv. Massai and 12 lots of cv. Tanzania.

Lots	EF	G	FGC	GSI	ES	FEC	SL	RL	ISL	Indexs	
	----------- % ----------				----- % -----		cm seedling $^{-1}$			VI	UI
					Panicum maximum cv. Massai						
1	39^{A}	79^{A}	59^{B}	23.53^{A}	53^{D}	42^{C}	2.9^{A}	3.9^{A}	6.49^{C}	702^{C}	746^{B}
2	38^{A}	68^{C}	31^{C}	15.95^{C}	64^{C}	24^{D}	1.9^{B}	2.6^{B}	7.48^{B}	772^{C}	735^{B}
3	36^{A}	78^{A}	73^{A}	25.06^{A}	73^{B}	68^{A}	2.8^{A}	3.9^{A}	7.51^{B}	829^{B}	837^{A}
4	35^{A}	59^{D}	23^{D}	13.67^{D}	67^{B}	34^{C}	2.4^{A}	3.9^{A}	6.40^{C}	678^{C}	672^{C}
5	33^{A}	80^{A}	75^{A}	14.98^{A}	80^{A}	75^{A}	3.5^{A}	4.8^{A}	8.39^{A}	896^{A}	866^{A}
6	31^{A}	58^{D}	38^{C}	15.86^{C}	59^{C}	48^{B}	2.1^{B}	3.4^{A}	8.18^{A}	812^{B}	683^{C}
7	30^{A}	73^{B}	52^{B}	22.04^{B}	62^{C}	41^{C}	2.5^{A}	3.6^{A}	6.86^{C}	715^{C}	698^{C}
8	30^{A}	69^{C}	20^{D}	16.27^{C}	53^{D}	9^{D}	2.0^{B}	2.7^{B}	5.12^{D}	576^{D}	665^{C}
9	28^{B}	79^{A}	37^{C}	20.19^{B}	61^{C}	29^{C}	2.1^{B}	3.3^{A}	7.55^{B}	774^{C}	725^{B}
10	21^{B}	76^{A}	73^{A}	24.94^{A}	60^{C}	53^{B}	1.4^{B}	2.7^{B}	7.71^{B}	824^{B}	832^{A}
11	21^{B}	57^{D}	26^{D}	13.80^{D}	46^{D}	20^{D}	1.6^{B}	2.0^{B}	7.51^{B}	715^{C}	540^{D}
CV%	21.98	3.64	11.13	6.58	11.51	22.96	22.70	28.95	9.27	6.72	6.26
					Panicum maximum cv. Tanzânia						
1	47^{a}	55^{c}	5^{d}	10.60^{c}	60^{b}	62^{b}	1.9^{b}	4.4^{a}	6.34^{c}	727^{b}	785^{a}
2	46^{a}	70^{a}	36^{a}	19.05^{a}	78^{a}	82^{a}	2.1^{b}	4.7^{a}	7.24^{b}	762^{b}	762^{a}
3	44^{a}	65^{a}	31^{b}	16.90^{a}	70^{a}	77^{a}	3.0^{a}	4.4^{a}	7.92^{a}	814^{a}	768^{a}
4	40^{b}	45^{c}	24^{c}	12.42^{c}	61^{b}	60^{b}	1.8^{b}	5.5^{a}	7.25^{b}	743^{b}	695^{b}
5	38^{b}	65^{a}	40^{a}	17.71^{a}	72^{a}	76^{a}	2.2^{a}	5.3^{a}	7.49^{b}	793^{a}	802^{a}
6	34^{b}	58^{b}	29^{b}	14.80^{b}	55^{b}	60^{b}	2.4^{a}	5.3^{a}	6.56^{c}	705^{b}	695^{b}
7	32^{b}	50^{c}	37^{a}	14.49^{b}	42^{c}	44^{c}	1.1^{c}	2.2^{b}	6.30^{c}	647^{c}	602^{c}
8	25^{c}	58^{b}	23^{c}	13.85^{b}	58^{b}	52^{b}	2.6^{a}	3.5^{b}	6.95^{b}	739^{b}	757^{a}
9	23^{c}	46^{c}	4^{d}	9.02^{d}	43^{c}	36^{c}	1.9^{b}	2.7^{b}	5.01^{e}	541^{d}	574^{d}
10	21^{c}	43^{c}	3^{d}	7.44^{d}	39^{c}	31^{c}	2.6^{a}	4.3^{a}	5.02^{e}	558^{d}	630^{c}
11	20^{c}	46^{c}	10^{d}	9.28^{d}	41^{c}	26^{c}	1.4^{c}	3.3^{b}	4.76^{e}	512^{d}	539^{d}
12	18^{c}	49^{c}	8^{d}	9.42^{d}	46^{c}	29^{c}	2.0^{b}	3.1^{b}	5.73^{d}	598^{c}	586^{d}
CV%	18.28	9.93	16.90	11.25	14.54	19.86	20.03	20.89	9.09	7.46	6.62

Averages followed by the same letter in the column do not differ by the Scott-Knott test ($p \leq 0.05$).

The germination of seeds from all lots was greater than 40%, which means that these could be commercialized as they are above the limits established by the Official Standards for the commercialization of *Panicum maximum* seeds (Brasil 2008). The germination of the lots varied between 57% and 80% and allowed them to be separated into four distinct quality classes.

Studies on vigor tests for cereal seeds such as millet (Machado et al. 2012) and corn (Grzybowski et al. 2015) prescribe that these have the function of differentiating seed lots with similar germination percentages. For species of tropical forage grasses, this premise is difficult to be fulfilled, as the seed lots of these species showed more divergent germination than those verified for those of large crops (Ohlson et al. 2011).

The germination test and the other vigor tests used were able to detect differences in the physiological potential of the seeds, however the ranking of the seed lots was different from that verified in the emergence of seedlings in the field.

Some vigor tests were sensitive in the cultivar Massai, classifying the seed lots into four vigor classes, the first germination count, germination speed index, seedling emergence in sand, first emergence count in sand and images analysis (seedling length, vigor and uniformity indexes). Other vigor tests were less rigorous and classified the lots into two classes in a similar way to the emergence of seedlings in the field, such as those of shoot and root lengths. Considering the 11 lots studied in the univariate analysis, the tests that presented results similar to those obtained in the emergence of seedlings in the field were those of shoot and root lengths that with approximately 73% coincidence in the classification of the seed lots.

For the cultivar Tanzania, the seed lots could be classified into more than three vigor classes, based on the first germination count, germination speed index and image analysis (seedling length, vigor and uniformity indexes). However, some tests showed divergence in the vigor classification of the lots, making it difficult to interpret the results. Based on the results of the univariate analysis to compare the means, it was verified for the 12 evaluated lots, that the seedling emergence tests in sand and the first seedling emergence count in sand were the most efficient, as they presented 67% of the results similar to those obtained in the emergence of seedlings in the field.

Seeds with higher physiological quality have greater speed in metabolic processes, providing faster and uniform seedling germinations (Munizzi et al. 2010). The greater the number of seedlings counted in the first count, the greater the physiological potential of the seed lot, as in general it indicates a greater correspondence with the number of seedlings in the field (Marcos Filho 2015).

According to Amaro et al. (2015) and Medeiros et al. (2018), the seedling length test or the length test of its parts has been considered to detect differences in the physiological potential of seeds of different species. The seedling length test is based on the fact that the most vigorous seeds give rise to more developed seedlings, due to their greater capacity for tissue transformation and stored reserves, being then efficient in assessing vigor (Amaro et al. 2015).

The large number of seed lots and quality parameters for both cultivars represent an obstacle to studies with univariate statistical analysis on seed vigor tests and, in these cases, cluster analysis produces better results (Barbosa et al. 2013; Silva et al. 2017; Pereira et al. 2020). Therefore, the Euclidean distance five was adopted in the hierarchical cluster analysis by the Ward method and the seed lot quality assessment tests were separated into three groups (Hair et al. 2005) (Figure 1A and B).

For cultivar Massai, in group I, the root length, shoot length and seedling emergence variables in the field were concentrated (Figure 1A). While for the cultivar Tanzania in group I, the variables vigor index, seedling length, uniformity index, first seedling emergence count in sand, emergence of seedlings in sand and emergence of seedlings in the field were concentrated (Figure 1B). These were the ones that stood out the most, since the joint analysis of the lots resulted in high agreement in the classification of the seed lots and within this group is the seedling emergence in the field test.

Group II of cultivar Massai was formed by seedling emergence in sand, uniformity index, first seedling emergence count in sand, first germination count, germination speed and germination index, showing that these were similar to each other in the classification of the lots, but differ from those in group I. Group III was composed of the results of the variables, vigor index and seedling length, which showed greater distance and divergence compared to the others (Figure 1A).

In a different way, for cultivar Tanzania in group II, it was formed by the variable's germination speed index, first germination count and germination. In group III it was composed of the variables shoot length and root length.

The cluster analysis allowed an evaluation of the similarity between the variables considering their characteristics simultaneously. According to Hair et al. (2005) this technique gathers individuals, or seed lots as in the present study, in groups with greater similarity.

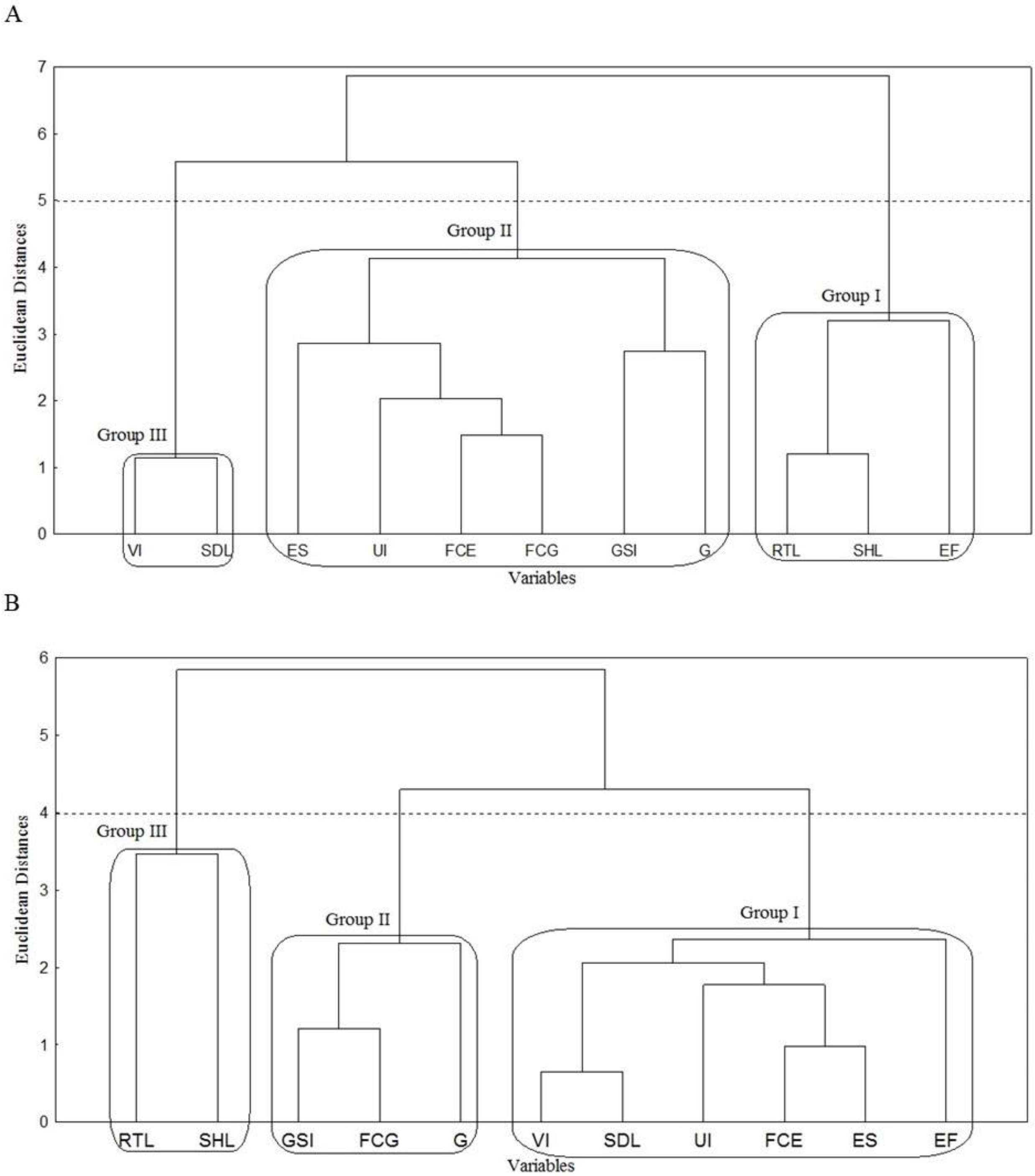

Figure 1. The dendrogram resulting from the hierarchical cluster analysis using Ward's method with the formation of groups based on emergence in the field (EF), germination (G), first germination count (FCG), germination speed index (GSI), seedling emergence in sand (ES), first seedling emergence count in sand (FCE), shoot length (SHL), root length (RTL), image analysis of seedling length (SDL), vigor index (VI) and uniformity index (UI) of 11 seed lots of *Panicum maximum* cv. A – Massai; B – 12 lots cv. Tanzania.

Two components were needed with a variance of 54.98% and 19.23%, respectively, to explain the variability of data from the analysis of principal components of the 11 lots of the cultivar Massai; 73.06% and 11.76% for the 12 lots of cultivar Tanzania, respectively (Table 3). Therefore, two principal components were sufficient in discriminating 74.21% and 84.82% of the parameters evaluated in the two cultivars.

Table 3. Correlation between each principal component and the physiological quality assessment tests of 11 lots of *Panicum maximum* cvs. Massai and Tanzania seeds.

Seed quality assessment tests	Principal Component	
	1	2
Panicum maximum cv. Massai		
Germination	-0.73	-0.26
First Germination Count	-0.88	0.27
Germination speed index	-0.46	0.11
Emergence in sand	-0.83	-0.11
First Germination Count	-0.93	0.22
Root length	-0.81	-0.46
Shoot length	-0.72	-0.55
Emergence in field	-0.39	-0.74
Length of seedlings	-0.50	0.71
Uniformity index	-0.91	0.05
Vigor index	-0.75	0.58
Eigenvalues	6.05	2.12
Total Variance (%)	54.98	19.23
Cumulated Variance	54.98	74.21
Panicum maximum cv. Tanzânia		
Germination	-0.89	-0.09
First Germination Count	-0.76	-0.52
Germination speed index	-0.90	-0.37
Emergence in sand	-0.96	0.06
First Germination Count	-0.98	-0.02
Root length	-0.65	0.49
Shoot length	-0.42	0.75
Emergence in field	-0.85	-0.08
Length of seedlings	-0.95	-0.06
Uniformity index	-0.91	0.25
Vigor index	-0.97	0.03
Eigenvalues	8.04	1.29
Total Variance (%)	73.06	11.76
Cumulated Variance	73.06	84.82

In studies on vigor tests for guinea grass seeds (Pereira et al. 2020), piata grass seeds (Silva et al. 2017) and decumbens grass seeds (Silva et al. 2019) it was also found that two principal components would be enough to explain 79.08%; 74.23% and 73.47%, respectively, of the variance in the discrimination of the variables.

The discriminatory power of the variables in each principal component is measured by the correlation value (Hongyu et al. 2016). Thus, it was possible to infer those high correlations were found between all variables in principal components 1 or 2, except for the variable germination speed index observed for cultivar Massai and root length in cultivar Tanzania, which showed a correlation below 0,7 in both components (Hair et al. 2005). Therefore, these vigor tests were considered to have little relevance for the discrimination of *Panicum maximum* seed lots.

In cultivar Massai it was verified that the variables germination (-0.70), first germination count (-0.88), seedling emergence in sand (-0.84), first seedling emergence count in sand (-0 , 95), root length (-0.81), shoot length (-0.73) and image analysis for uniformity index (-0.76) and vigor index (-0.90) correlated significantly with the principal component 1. The seedling emergence test in the field and the image analysis for seedling length correlated better with the principal component 2, presenting values of 0.74 and -0.72, respectively.

While for cultivar Tanzania it was observed that the variables germination (-0.89), first germination count (-0.76), germination speed index (-0.90), seedling emergence in sand (-0.96), first emergence count in sand (-0.98), seedling emergence in the field (-0.85) and image analysis for seedling length (-0.95), uniformity index (-0.91) and vigor index (-0.97) were correlated with the principal component 1. The shoot length test (0.75) was better correlated with the principal component 2. The principal component 1 should be considered to have more relevance than 2, as it was able to explain 73.06% of the total data variability (Hair et al. 2005). Principal component 2 was able to explain only 11.76% of the total variability of the data.

It should be noted that the image analysis tests for seedling length, vigor index and growth uniformity index and the traditional seedling emergence tests in sand, first seedling emergence count in sand and seedling emergence in the field, showed greater similarity to each other, as they belong to the same group when using multivariate analysis (Figure 1B).

In the principal components analysis (Figure 2A), it was found that the root and shoot length tests of Massai seedlings showed to be the vectors closest to the vector of seedling emergence in the field and these tests had been inserted in the same group by cluster analysis (Figure 1A). These results confirmed those verified in the comparison of averages in Table 2, but in a simplified and evident way.

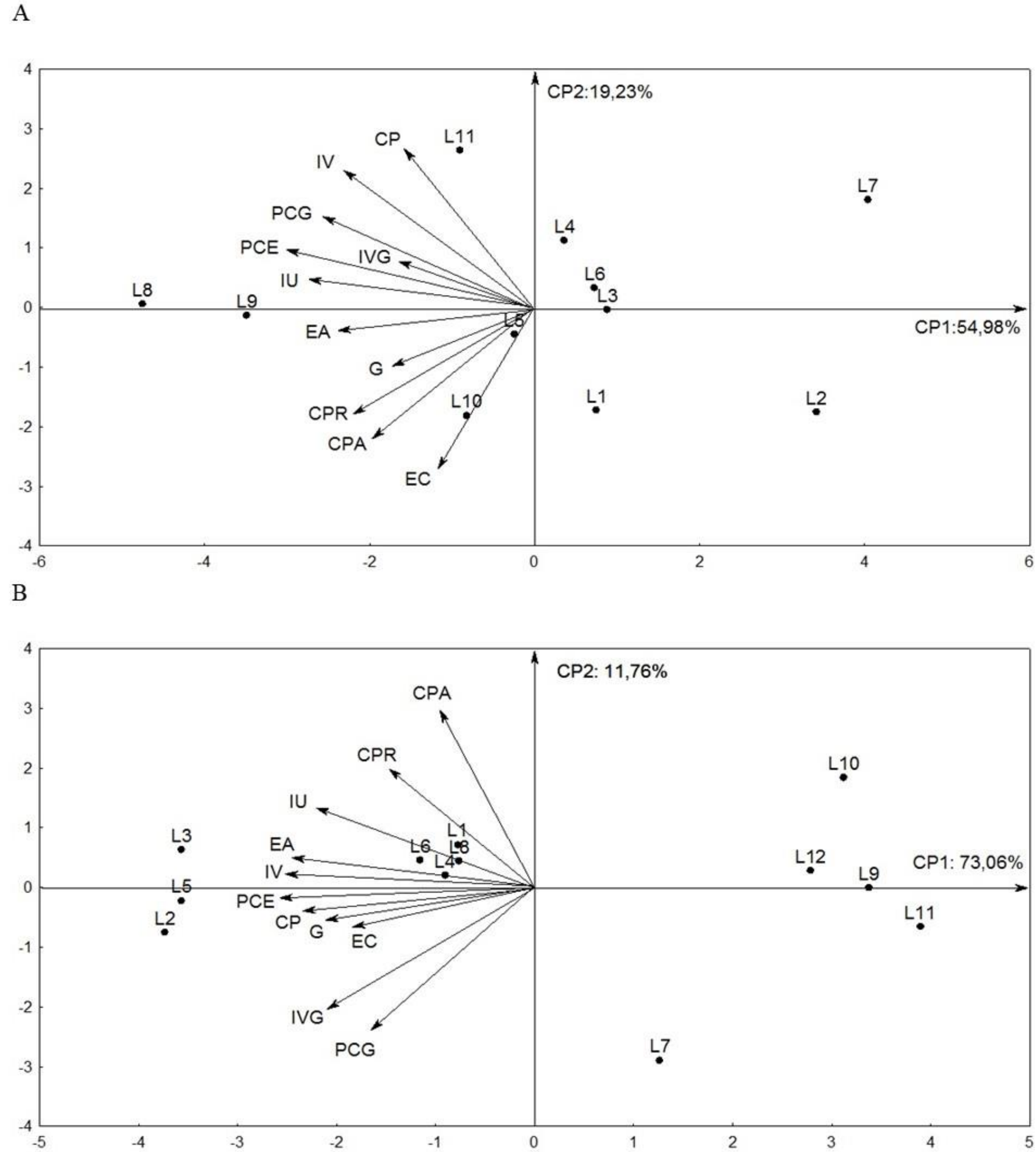

Figure 2. Eigenvectors, dispersion plan through the analysis of principal components of the emergence in the field (EF), germination (G), first germination count (FCG), germination speed index (GSI), seedling emergence in sand (ES), first seedling emergence count in sand (FCE), shoot length (SHL), root length (RTL), image analysis of seedling length (SDL), vigor index (VI) and uniformity index (UI) of 11 seed lots of *Panicum maximum*, cvs. A – Massai; B – Tanzania.

From the analysis of the dispersion plan of Tanzania grass (Figure 2B), it was found that the tests located in the principal component 1 (germination, first germination count, germination speed index, emergence of seedlings in sand, first count emergence of seedlings in sand, and image analysis for seedling length, uniformity index and vigor index) were promising in the evaluation of seed lots aiming to rank them in terms of vigor and seedling emergence in the field.

Similar to the present study, other studies on vigor tests of rice seeds, piata grass, decumbens grass and guinea grass had shown greater adequacy and efficiency when using multivariate analysis compared to univariate analysis when large numbers of seed lots and parameters were evaluated (Lorentz and Nunes 2013; Silva et al. 2017; Silva et al. 2019; Pereira et al. 2020).

4. Conclusions

The shoot and root length tests are efficient for the evaluation of physiological potential of *Panicum maximum* cv. Massai, while seedling length, vigor index and growth uniformity index tests using image analysis, seedling emergence in sand and first seedling emergence count in sand are efficient in assessing the physiological potential of seeds of *Panicum maximum* cv. Tanzania, providing information similar to seedling emergence in the field.

Authors' Contributions: PEREIRA, F.E.C.B.: conception and design, acquisition of data, analysis and interpretation of data, drafting the article; JEROMINI, T.S.: analysis and interpretation of data, acquisition of data drafting the article; SILVA, G.Z.: analysis and interpretation of data; TORRES, S.B.: analysis and interpretation of data; MARTINS, C.C.: analysis and interpretation of data. All authors have read and approved the final version of the manuscript.

Conflicts of Interest: The authors declare no conflicts of interest.

Ethics Approval: Not applicable.

Acknowledgments: The authors would like to thank the funding for the realization of this study provided by the Brazilian agencies CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil), Finance Code 001, and CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico - Brasil).

References

AMARO, H.T.R., et al. Testes de vigor para avaliação da qualidade fisiológica de sementes de feijoeiro. *Revista de Ciências Agrárias*. 2015, **38**(3), 383-389.

BARBOSA, R.M., et al. D. Discrimination of soybean seed lots by multivariate exploratory techniques. *Journal of Seed Science*. 2013, **35**(3), 302-310. https://doi.org/10.1590/S2317-15372013000300005

BRASIL. Ministério da Agricultura, Pecuária e do Abastecimento. *Instrução Normativa nº 30, de 21 de maio de 2008.* Diário Oficial da União: Poder Executivo, 2008.

BRASIL. Ministério da Agricultura, Pecuária e Abastecimento: *Regras para Análise de Sementes*. Brasília: Secretaria de Defesa Agropecuária, 2009.

CARVALHO, N.M. and NAKAGAWA, J. *Sementes: ciência, tecnologia e produção*. Jaboticabal: FUNEP, 2012.

DUTRA, J.C. and RODRIGUES, A.P.D.C. and PEREIRA, S.R. Heat treatment to overcome seeds dormancy of *Panicum maximum* cultivars (Poaceae). *African Journal of Agricultural Research*. 2015, **10**(50), 4616-4622. https://doi.org/10.5897/AJAR2015.10217

GOMES-JUNIOR, F.G. and CICERO, S.M.X. Ray analysis to assess mechanical damage in sweet corn seeds. *Revista Brasileira de Sementes*. 2012, **34**(1), 78-85. https://doi.org/10.1590/S0101-31222012000100010

GRZYBOWSKI, C.R.S. and VIEIRA, R.D. and PANOBIANCO, M. Testes de estresse na avaliação do vigor de sementes de milho. *Revista Ciência Agronômica*. 2015, **46**(3), 590-596. https://doi.org/10.5935/1806-6690.20150042

HAIR, J.F., et al. *Análise multivariada de dados*. 5th ed. Porto Alegre: Bookman, 2005.

HOFFMASTER, A.L., et al. An automated system for vigor testing three-day old soybean seedlings. *Seed Science and Technology*. 2003, **31**(3), 701-713.

HONGYU, K. and SANDANIELO, V.L.M. and OLIVEIRA JUNIOR, G.J. Análise de componentes principais: resumo teórico, aplicação e interpretação. *Engineering and Science*. 2016, **15**(1), 83-90. http://dx.doi.org/10.18607/ES201653398

JEROMINI, T.S., et al. The use of X-ray to evaluate *Brachiaria brizantha* seeds quality during seed processing.*Revista Ciência Agronômica*. 2019, **50**(3), 439-446. https://doi.org/10.5935/1806-6690.20190052

JOHNSON, R.A. and WICHERN D.W. *Applied multivariate statistical analysis*. 3rd ed. New Jersey: Prentice Hall, 1998.

KAISER, H.F. The varimax criterion for analytic rotation in factor analysis. *Psychometrika.* 1958, **23**, 187-200. https://doi.org/10.1007/BF02289233

LORENTZ, L.H. and NUNES, U.R. Relações entre medidas de qualidade de lotes de sementes de arroz. *Revista Ciência Agronômica*. 2013, **44**(4), 798-804. https://doi.org/10.1590/S1806-66902013000400017

MACHADO, C.G., et al. Precocidade na emissão da raiz primária para avaliação do vigor de sementes de milheto. *Semina: Ciências Agrárias.* 2012, **33**(2), 499-506. https://doi.org/10.5433/1679-0359.2012v33n2p499

MAGUIRE, J.D. Speed of germination aid in selection and evaluation for seedling and vigour. *Crop Science.* 1962, **2**(2) 176-177. http://dx.doi.org/10.2135/cropsci1962.0011183X000200020033x

MARCOS FILHO, J. and KIKUTI, A.L.P. and LIMA, L.B. Métodos para avaliação do vigor de sementes de soja, incluindo a análise computadorizada de imagens. *Revista Brasileira de Sementes*. 2009, **31**(1), 102-112. https://doi.org/10.1590/S0101-31222009000100012

MARCOS FILHO, J. *Seed Physiology of Cultivated Plants*. Londrina: ABRATES, 2016.

MARCOS FILHO, J. Seed vigor testing: an overview ofthepast, presentand future perspective. *Scientia Agricola*. 2015, **72**(4), 363-374. https://doi.org/10.1590/0103-9016-2015-0007

MEDEIROS, A.D., PEREIRA, M.D. and SILVA, J.A. Processamento digital de imagens na determinação do vigor de sementes de milho. *Revista Brasileira de Ciências Agrárias*. 2018, **13**(3), 1-7. https://doi.org/10.5039/agraria.v13i3a5540

MELO, L.F., et al. Beneficiamento na qualidade física e fisiológica de sementes de capim-mombaça. *Revista Ciência Agronômica*. 2016, **47**(4), 667-674. https://doi.org/10.5935/1806-6690.20160080

MELO, P.A.F.R., et al. Vigor tests in assessing the quality of signal grass seeds**.** *Semina: Ciências Agrárias.* 2017, **38**(6), 3491-3498. https://doi.org/10.5433/1679-0359.2017v38n6p3491

MENDONÇA, V.Z., et al. Corn production for silage intercropped with forage in the farming-cattle breeding integration. *Engenharia Agrícola.* 2014, **34**(4), 738-745. https://doi.org/10.1590/S0100-69162014000400013

MUNIZZI, A., et al. Qualidade de sementes de quatro cultivares de soja, colhidas em dois locais no estado de Mato Grosso do Sul. *Revista Brasileira de Sementes.* 2010, **32**(1), 176-185. https://doi.org/10.1590/S0101-31222010000100020

OHLSON, O.C., et al. Qualidade física e fisiológica de sementes de capim-colonião e milheto, comercializadas no estado do Paraná. *Informativo ABRATES.* 2011, **21**(3), 52-56.

OLIVEIRA, S.S.C., et al. Seleção de progênies de nabo-forrageiro para germinação sob altas temperaturas. *Ciência Rural.* 2014, **44**(2), 217-222.

OLIVEIRA, S.S.C., et al. Tests for the selection of forage turnip progeny to order the vigor and longevity of seeds. *Revista Caatinga*. 2017, **30**(1), 230-236. https://doi.org/10.1590/1983-21252017v30n125rc

PEREIRA, F.E.C.B., et al. Tests to evaluate the physiological potential of Mombasa grass seeds. *Revista Ciência Agronômica*. 2020, **51**(1), e20186359. https://doi.org/10.5935/1806-6690.20200009

SILVA, G.Z., et al. Evaluation the physiological quality of *Brachiaria brizantha* cv. BRS 'Piatã' seeds. *Bioscience Journal.* 2017, **33**(3), 572-580. https://doi.org/10.14393/BJ-v33n3-36519

SILVA G.Z., et al. Phytosanitary quality of *Brachiaria brizantha* 'BRS Piatã' seeds in function of climate conditions *Revista Brasileira de Engenharia Agrícola e Ambiental.* 2019, **33**(4), 237-243. https://doi.org/10.1590/1807-1929/agriambi.v23n4p237-243

SNEATH, P.H.A. and SOKAL, R.R. *Numerical taxonomy*. San Francisco: W.H. Freeman, 1973.

SOUZA, G.E., et al. Comparação entre métodos para a avaliação de vigor de sementes de algodão. *Revista de Agricultura Neotropical.* 2014, **1**(2), 35-41. https://doi.org/10.32404/rean.v1i2.237

TOMAZ, C.A., et al. Time reduction for surinam grass seed germination test. *Ciência e Agrotecnologia.* 2015, **39**(5), 488-497. https://doi.org/10.1590/S1413-70542015000500007

Received: 13 April 2020 | **Accepted:** 8 October 2021 | **Published:** 31 March 2022