doi:10.14720/aas.2023.119.3.13508 Original research article / izvirni znanstveni članek

Relationship between laboratory and field assessments of common bean (*Phaseolus vulgaris* L.) seed quality indicators

Albert T. MODI [1, 2]

Received March 05, 2023; accepted August 06, 2023.
Delo je prispelo 5. marca 2023, sprejeto 6. avgusta 2023

Relationship between laboratory and field assessments of common bean (*Phaseolus vulgaris* L.) seed quality indicators

Abstract: The objective of this study was to extend the measure of seed quality beyond seed germination using three common bean (*Phaseolus vulgaris*. L) cultivars. Under laboratory conditions, total seed germination was included in calculation of other seed performance measures, mean germination rate and germination vigour index. These parameters were used to produce a new parameter, total potential value for germination. The laboratory measures were duplicated under field conditions over two seasons to produce comparable data for seedling emergence, mean emergence rate and emergence vigour index. Consequently, total potential value for emergence was derived. The crop was grown under field conditions at three seeding rates (177 000 plants ha^{-1}, 150 000 plants ha^{-1} and 115 000 plants ha^{-1}). Prediction of seed performance under field conditions was extended by measuring plant size from the first trifoliate to initiation of reproductive stage. During this period, new measures comparable to those of laboratory seed vigour and emergence vigour were derived on the basis of vegetative growth vigour, resulting in total potential value of plant growth. The study revealed that germination and plant growth can be correlated using vigour indices.

Key words: emergence, germination, growth index, seed vigour

Razmerje med laboratorijskimi in poljskimi indikatorji kakovosti semen navadnega fižola (*Phaseolus vulgaris* L.)

Izvleček: Namen raziskave je bil določiti poleg kalitve še dodatne kakovostne indikatorje semen treh sort navadnega fižola (*Phaseolus vulgaris*. L). V laboratorijskih razmerah je bila celokupna kalivost semen vključena v izračun dodatnih meril določanja kakovosti semen kot sta poprečna kalivost in indeks kalitvenega vigorja. Ti parametri so bili uporabljeni za izdelavo novega parametra, imenovanega celukopni potencial kalitve. Laboratorijski postopki so bili podvojeni v razmerah poljskega poskusa v dveh rastnih sezonah za pridobitev primerljivih podatkov za vznik kalic, poprečno vrednost vznika in indeks vigorja vznika. Iz teh podatkov je bila izračunana poprečna celokupne vrednost vznika. Posevek je rastel v treh gostotah (177 000 rastlin ha^{-1}, 150 000 rastlin ha^{-1} in 115 000 rastlin ha^{-1}). Napoved uspešnosti rasti v poljskih razmerah je bila narejena na meritvah velikosti rastlin of prvega trojnatega lista do začetka reproduktivne faze razvoja. V tem obdobju so bila pridobljena merila za vigor rasti in celokupno potencialno vrednost rasti podobna tistim v laboratoriju, ki so določala vigor semen in vznika. Raziskava je pokazala, da bi kalitev in rast rastlin lahko korelirali z uporabo indeksov vigorja.

Ključne besede: vznik, kalitev, indeks rasti, vigor semen

1 School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal, Pietermaritzburg, South Africa
2 Corresponding author, e-mail: albertmodi6@gmail.com

1 INTRODUCTION

Seed quality is an important determinant of plant genetic material performance under a wide range of environmental conditions. Its assessment can be done to fit the purpose of the researcher in the laboratory where quick physiological responses can be adequate. However, for purposes of commercial crop production and long-term genetic preservation, it is necessary to use a reliable method whose results can be interpreted meaningfully and linked to crop or germplasm performance to protect the plant breeder, the seed market, and the farmer (Bishaw & Turner, 2008; Fajardo et al., 2010; Francki et al., 2021). Seed germination has been tested and accepted as a reliable method to test seed quality. To accommodate its limitations, which can be linked to the effects of environment e.g., temperature, moisture as well as pre-and post-harvest growth and management conditions (Louwaars & Manicad, 2022), international standards accept seminal root protrusion as a baseline indicator of quality in the context of laboratory seed germination.

However, good seed quality is expected to provide a significant genotypic contribution of crop resilience to environmental conditions associated with soil, weather and management conditions of the farm. Seed germination is the basic measure of seed quality recognised by scientists and producers. Previous studies have shown that seed germination response can be expanded to determine other laboratory related parameters, mainly seed vigour, which is based on germination rate and seedling size (Farshid et al., 2019; Hassani et al., 2019). Hence, germination and vigour are commonly used together for quality determination because they are linked. However, seed germination can be used independently to recommend crop potential performance under field conditions (Beveridge, 2020). For example, it is estimated that rapid seminal root protrusion under laboratory conditions must be a minimum of 90 % for it to be considered for optimum production, but 100 % seed germination is required (Allen & Meyer 1990, 1998; Rajendndra, 2023). However, there is no conclusive evidence that seed germination parameters are always linked to crop establishment, growth and final yield (Ellis, 1992). It is generally accepted that relating seed quality directly with plant performance parameters is difficult to achieve. This relationship may be implicitly indicated by special definition of vigour. Previous studies have indicated that this relationship can be shown in theory. It was suggested that seed germination, vigour and size are three aspects of quality that may indirectly influence percentage emergence and time from sowing to emergence (Ellis, 1992). These factors may implicitly influence yield by altering plant population density, spatial arrangement, and crop performance. Seed vigour has become a reliable seed quality measure to confirm results of seed quality, including genetics, for both cultivated and other plant species (Priyanka et al., 2019). Previous studies have shown that plant population affects growth and yield (Ihsanullah et al., 2002). In view of rapidly changing environmental rigours for crop production, due to climate change, it is important to trace and relate seed quality aspects from the laboratory to a wide range during crop growth and development (Akinci et al. 2008; Singh, 2014). Hence, the objective of this study was to provide a practical method of explaining the concept of seed quality based on laboratory and field-based methods in order to produce new indices that have not been shown in seed science studies before.

2 MATERIALS AND METHODS

2.1 LABORATORY SEED QUALITY DETERMINATION

Fresh seeds of three common bean cultivars, Ukulinga, Gadra and Mthatha were donated by Pro-seed cc (https://www.africanadvice.com) from a plant breeding stock. Seed germination percent (G), shown as seminal root protrusion, was determined according to International Seed Testing Association guidelines (ISTA, 2013) for a total period of seven (7) days. The paper towel method was used at 25 °C and replicated four times, with 25 seeds per replication. In addition, mean germination rate (MGR) and germination vigour index (GVI) were determined according to modification of Thanuja et al. (2019).

For mean germination rate:

$$MGR = (\Sigma D n)/ (\Sigma n) \qquad \text{(Equation 1)}$$

Where, MGR is mean germination rate, D is the number of days from the beginning of germination, and n is the number of seeds that have germinated on day D. This value indicates the average rate of seed germination as indicated by seminal root protrusion.

For germination vigour index (GVI):

$$GVI = G1/N1 + G2/N2 + \ldots + Gn/Nn \qquad \text{(Equation 2)}$$

Where, G1, G2…Gn = number of germinated seeds in the 1st, 2nd… last count (n), and N1, N2…Nn = number of germination days at the 1st, 2nd… last count (n). This value indicates the rate of germination daily. Laboratory seed quality was taken to have different aspects from minimum (G), moderate (MGR) and high (GVI) indicator, respectively. The reason for this was that the value of germination is incrementally improved by considering the rate (MGR) and then the rate combined with potential impression of physiological factors (Taiz et al., 2018, Takahashi et al. 2018) that affect robustness (GVI). To complete that seed quality view of aspects, the study calculated a new parameter, total potential value for germination (TPVg).

$$TPVg = GVI/N \qquad \text{(Equation 3)}$$

Where, GVI is germination vigour index (see equation 2 above) and N is the total germination period (7 days). This value indicates the number of seeds in relation to vigour.

2.2 FIELD TRIAL FOR SEED QUALITY DETERMINATION AND CROP GROWTH

A field trial was undertaken (29°37'45 S 30° 24' 17" E) and repeated during the normal planting season. The experimental design was a split-plot in a randomised complete block, replicated three times. There were two factors used, namely three intermediate growth cultivars (Ukulinga, Gadra and Mthatha) and three plant densities [high (177 000 plants/ha), medium (150 000 plants/ha) and low (115 000 plants/ha)]. The variables were emergence and above ground plant size (mm). Prior to planting, soil analysis was performed to determine suitable fertiliser application for common bean (Liebenberg, 2010).

2.3 SEED QUALITY DETERMINATION UNDER FIELD CONDITIONS

Seedling emergence was monitored daily for a period of seven (7) days from planting. Total emergence percent (E), mean emergence rate (MER), daily rate of emergence EVI and total potential value for seedling emergence (TPVe) were determined using the same formulae as for laboratory seed quality.

2.4 PLANT GROWTH PARAMETERS

From emergence, non-destructive evaluation of plant growth (cm) was determined. An average of five randomly selected plants per plot (two middle rows of a 2 m^2 area used as one replicate) was used to measure plant growth weekly, between VE (emergence) and R1 (initiation of flowering) (Rahman et al., 2011). Accordingly, plant growth (P) was monitored for seven (7) growth stages from the first trifoliate (V1) to initiation of reproductive stage (R1). Plant size (MPI) and plant growth vigour index (PVI) were used to calculate potential value for plant growth (TPVp) using the same formulae as for laboratory seed and emergence quality.

2.5 STATISTICAL ANALYSIS

Data were subjected to analysis of variance using GenStat® Version 18 (VSN International, United Kingdom) at the 5 % probability level ($p \leq 0.05$). Duncan's Multiple Range test was used to compare means. There were no significant differences between seasons. Therefore, no data to compare the two growth seasons are shown.

3 RESULTS AND DISCUSSION

Cultivar differences with respect to germination were significant (p = 0.03), with 'Ukulinga' showing complete germination by the fourth day. 'Gadra' was better than 'Mthatha', but both of these cultivars did not rich 100 % germination. The trend of differences between cultivars was consistent throughout the germination period (Table 1). With respect to germination rate, differences between cultivars diminished over time, so that by the fourth day there were no significant differences (Table 1). High germination was associated with a steady germination rate, whereas delayed germination continued to have a high germination rate until the end of incubation period (Table 1). Cultivar differences with respect to emergence followed a similar trend to that of germination ($p = 0.01$). 'Ukulinga' showed complete emergence five days after planting, but all cultivars emerged completely seven days after planting (Table 1). Rate of emergence also showed a similar trend to that of germination (Table 1). Seeding rate had no effect on emergence.

For all cultivars germination was highly significantly correlated with germination rate index (Figure 1A). Emergence was highly significantly correlated with emergence rate index (Figure 1B). Plant growth was highly significantly correlated with plant growth index (Figure 1C).

Plant growth from the first plant trifoliate to initial reproduction stage showed no significant differences between seeding rates and cultivars, overall (Figure 2).
When the total potential seed value for germination was compared with that for emergence and plant growth to flowering, it was clear that both emergence and plant growth are highly correlated with seed quality (Figure 3).

Table 1: Comparison common bean cultivars (Gadra, Mthatha and Ukulinga) with respect to germination (G) and emergence (E) as well as their respective daily rates (MGR and MER) over a period of seven days (Day 1 to Day 7) of laboratory incubation and field planting, respectively. Values sharing the same letters are not significantly different ($p \le 0.05$)

Variable	Cultivar	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
G	Gadra	0a	50b	80b	90b	95b	95b	95b
	Mthatha	0a	20a	60a	80a	90a	90a	90a
	Ukulinga	20b	60c	95c	100c	100c	100c	100c
MGR	Gadra	0a	0.16a	0.15a	0.18ab	0.21a	0.25a	0.29a
	Mthatha	0a	0.4b	0.2b	0.2b	0.22a	0.27a	0.31a
	Ukulinga	0.2b	0.13a	0.13a	0.16a	0.2a	0.24a	0.28a
Variable		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
E	Gadra	0a	0a	20a	60a	80a	100a	100a
	Mthatha	0a	0a	40b	85c	95b	100a	100a
	Ukulinga	0a	30b	60c	80b	100c	100a	100a
MER	Gadra	0a	0a	1c	0.44b	0.42b	0.4a	0.47a
	Mthatha	0a	0a	0.5b	0.31a	0.35a	0.4a	0.47a
	Ukulinga	0a	0.44b	0.33a	0.33a	0.33a	0.4a	0.47a

Seed germination has been a reliable measure of seed quality in science and for agricultural production regardless of system (Sako et al., 2001). Both controlled environment nursery production and widely variable field conditions rely mainly on seed germination percent as the primary indicator of seed quality (Rahman et al., 2011). Over time, science has developed other measures of seed quality to test seed response to factors associated with harsh conditions for growth, including imbibition, high mineral content and suboptimal temperature and water conditions (Priyanka et al., 2019). This led to seed vigour being an additional seed quality measure closely associated with seed germination (ISTA, 2013). The usefulness of other seed quality measures associated with germination is generally limited to laboratory experiments and decisions for micro-level interpretation of seed quality (Ellis, 1992; Farshid et al., 2019). This study attempted to expand the meaning of seed quality beyond relying on seed germination as the most important measure (Beveridge, 2020; Kildisheva et al., 2019). Advantage was taken of seed vigour determined by seed germination rate, which can also be linked to seedling size in the laboratory (Grafton et al., 1988). Seed germination was found to be directly linked to emergence, but it does not guarantee a perfect match in that emergence can be overestimated if one uses germination alone (Ambika et al., 2014). However, it was found useful to continue to use both germination (a clear indicator of seed viability in terms of seminal root protrusion under favourable conditions) and emergence (a clear indicator of the ability of seed to produce a seedling under optimum soil and climate conditions). A comparison of data in Table 1 with Figures 1A and 1 B clearly confirms this argument. Further, when plant size was related to growth rate (Figure 1C), there was a consistent comparison with what happened when germination and emergence were similarity related to what would be a direct physiological response to them, mean germination rate and mean emergence rate, respectively. This comparison allowed the basic measure of seed quality, germination to be indirectly linked to measures of plant performance under field conditions, regardless of cultivar or seeding rate (Figure 2).

Further consideration of all known laboratory seed quality indicators, germination, rate of germination and germination vigour index led to a new index of seed quality, total potential value for germination (TPVg). This index was directly comparable to those for field emergence (TPVe) (Figure 3). From these results, it can be assumed that the direct relationship between laboratory seed quality index with plant performance in the field is possible.

The study showed that it is possible to replicate seed vigour measures during the early stages of crop establishment. This was shown by the significant similarity of mean germination test results to mean emergence test, as well as germination vigour index and emergence vigour index. The reliability of these new comparisons between simple measures of seed quality (germination and emergence) led to the interest in producing more indirect measures of seed value that may be implicitly related to seed quality beyond germination and emergence. This study expanded the concept of emergence to crop establishment as well as growth and development under field

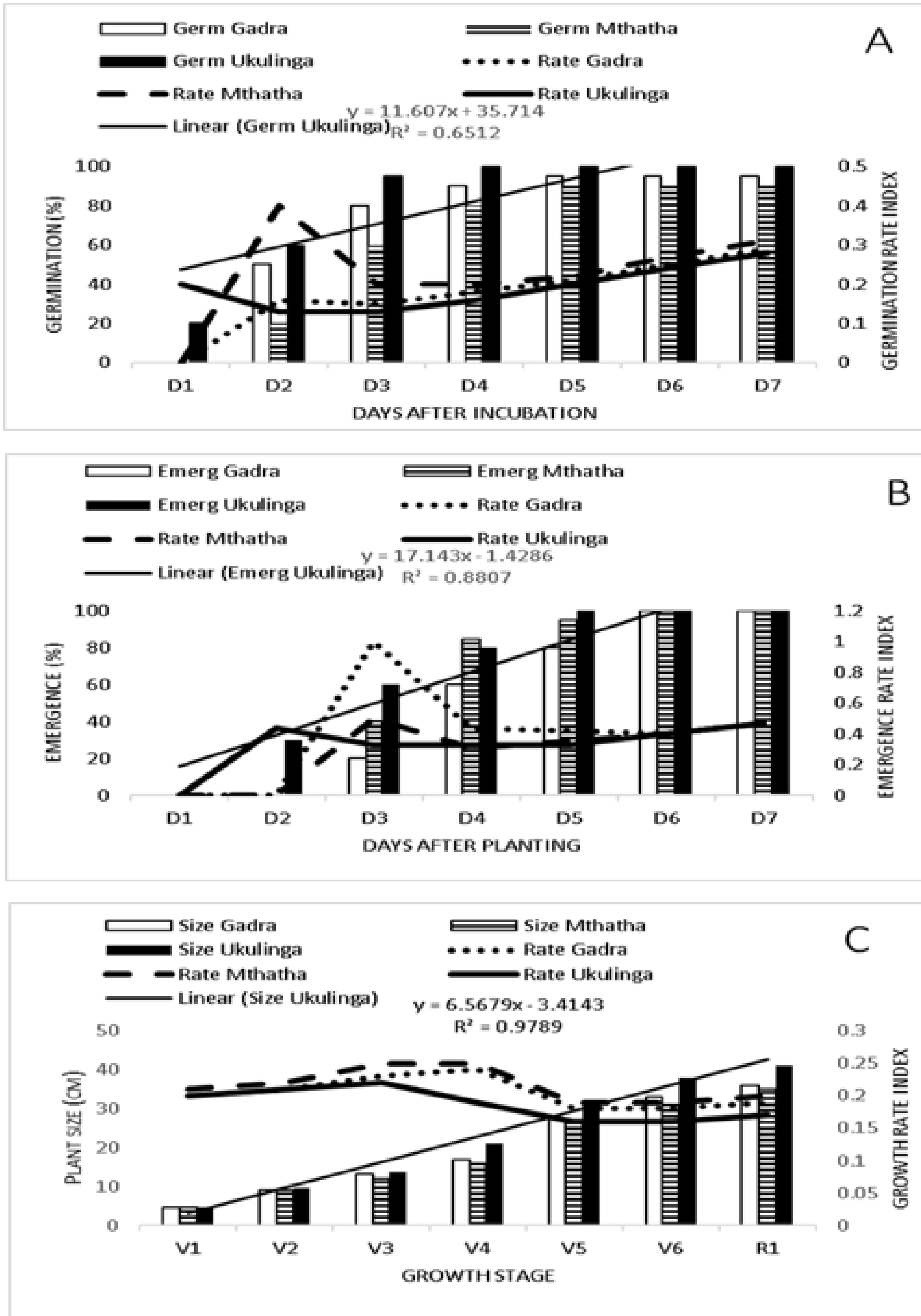

Figure 1: Comparison of germination (A) (Note: Germ = germination; Rate = germination rate), emergence (B) and plant size (C) with rates of seed germination, seedling emergence and plant growth, respectively. Germination and emergence occurred over a period of seven days (D1 to D7). Growth occurred over seven stages from the first trifoliate (V1) to initial reproduction (R1). Correlation across all parameters was indicated using cultivar Ukulinga mean values to represent the general trend

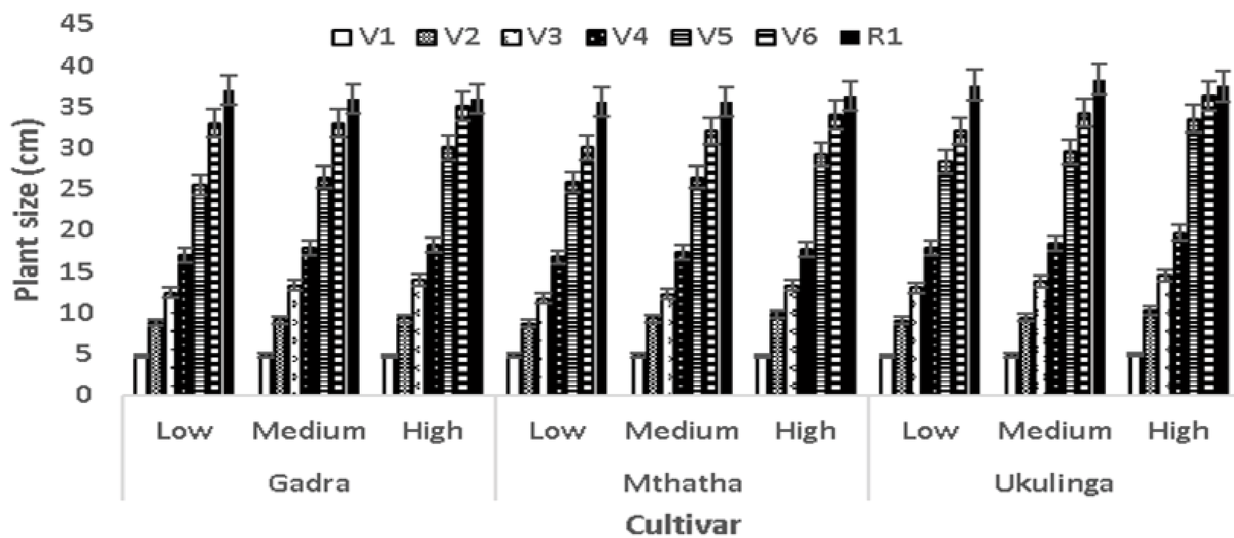

Figure 2: Plant size of three common bean cultivars (Gadra, Mthatha and Ukulinga) from first trifoliate (V1) to initiation of reproductive phase (R1) under different seeding rates (Low = 115 000 plants ha^{-1}, Medium = 150 000 plants ha^{-1} and High = 177 000 plants ha^{-1})

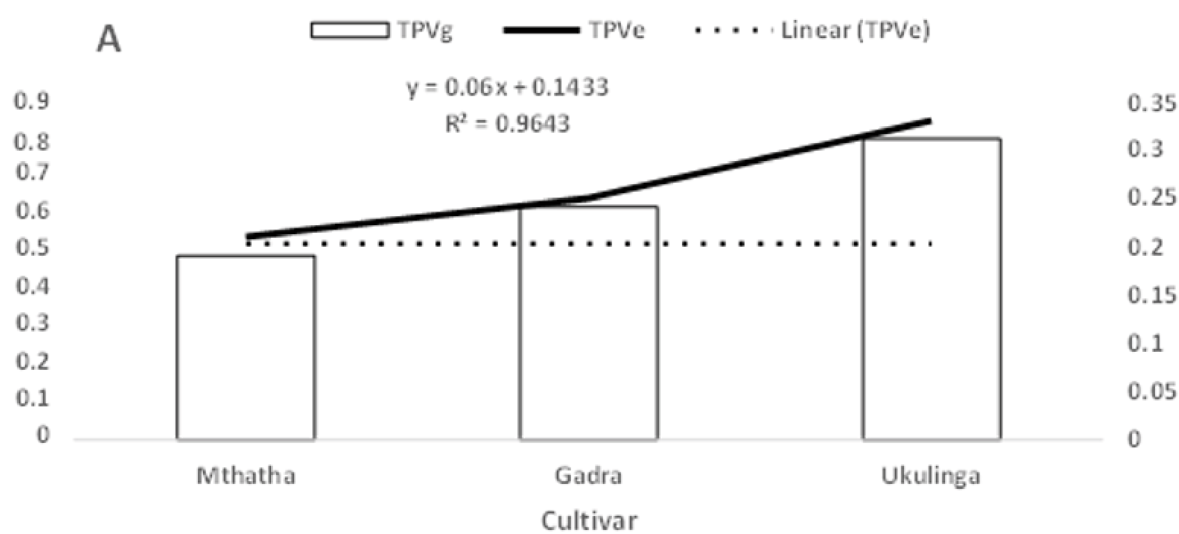

Figure 3: Relationship of total potential value of seed germination (TPVg; y-axis, 0 to 0.35) with those of emergence (TPVe; y-axis, 0 to 0.9) for three common bean cultivars

conditions using different cultivars and seeding rates (Grafton et al., 1988). Hence, the potential value of seed performance beyond germination was shown when a new measure of total potential value under germination (TPVg) was comparable to that derived for emergence (TPVe) and plant growth (TPVp). Both indicators were comparable to germination and emergence performances of the crop. Further, the study was able to show that following the monitoring of vegetative growth stages, a new index of perceived seed potential can be determined based on crop growth vigour sub-indices. The vegetative growth rate index and growth range index were derived simply from measurement of plant size in the field. In combination, they were useable to predict growth potential index.

4 CONCLUSION

The results of this study confirm the parameters for seed quality determination which are already accepted by the International Institute for Seed Testing Association

(ISSTA) based on the general parameters of germination and vigour. The combination of existing parameters using a simple model suggests that there may be three options to relate seed quality to potential seed performance. These indices have different values, but TPVe and TPVg are not very different in terms of linkage to basic seed quality, germination and emergence. The index associated with field growth and development indicated greater differences between cultivars. It may be less effective than the indices done closer to early stages of biological activity for seed. This study showed that there is consistency of the relationship between laboratory seed quality determination, seedling establishment, shown as emergence, and plant growth following emergence. It is a simple study that was designed to minimise variation in that related common bean genotypes and one site were used under a limited range of management conditions. The relative control of variation is necessary in experiments where new findings are a focus, instead of testing existing knowledge. The study concludes that there is a potential to expand seed quality determination beyond the simple germination and vigour indices under laboratory conditions. Total value potential (TPV) under laboratory and field conditions could be a new way of increasing knowledge about seed vigour. Expansion of this seed quality determinant to link it to field performance of the crop was encouraging. More research is needed to confirm the results under a wide range of genotypes and environmental or management conditions. Future studies should also determine the relationship between relevant crop performances that can be directly linked to interaction of plant physiology and yield.

5 REFERENCES

Akinci C., Yildirim M. & Bahar B. (2008). The effect of seed size on emergence and yield of durum wheat. *Journal of Food Agriculture and Environment, 6*(6), 234-237.

Allen P.S. & Meyer, S.E. (1990). Temperature requirements for reed germination of three *Penstemon* species. *HortScience, 25,* 191–193. https://doi.org/10.21273/HORTSCI.25.2.191

Allen P.S. & Meyer, S.E. (1998). Ecological aspects of seed dormancy loss. *Seed Science Research, 8,* 183–192. https://doi.org/10.1017/S0960258500004098

Ambika S., Manonmani V. & Somasundaram, G. (2014). Review on effect of seed size on seedling vigour and seed yield. *Research Journal of Seed Science, 7,* 31-38. https://doi.org/10.3923/rjss.2014.31.38

Beveridge F.C. (2020). Seed enhancement technologies to improve germination and emergence of Australian native Poaceae. *Seed Science Research, 30*(4)*, 293-303.* https://doi.org/10.1017/S0960258520000276

Bishaw Z. & Turner, M. (2008). Linking participatory plant breeding to the seed supply system. *Euphytica, 163,* 31- 44. https://doi.org/10.1007/s10681-007-9572-6

Ellis R. (1992). Seed and seedling vigour in relation to growth and yield. *Plant Growth Regulation, 11*(3)*,* 249-255. https://doi.org/10.1007/BF00024563

Fajardo J., Lutaladio N., Larinde M., Rosell, C., Roca W. & Chujoy, E. (2010). Quality declared planting material: protocols and standards for vegetatively propagated crops. FAO, Rome (Italia). https://www.sweetpotatoknowledge.org/files/quality-declared-planting-material-protocols-and-standards-for-vegetatively-propagated-crops/

Francki MG, Stainer GS, Walker E, Rebetzke GJ, Stefanova KT & French RJ (2021). Phenotypic evaluation and genetic analysis of seedling emergence in a global collection of wheat genotypes (*Triticum aestivum* L.) under limited water availability. *Frontiers in. Plant Science, 12*, 796176. https://doi.org/10.3389/fpls.2021.796176

Grafton K., Schneiter, A. & Nagle, B. (1988). Row spacing, plant population, and genotype× row spacing interaction effects on yield and yield components of dry bean. *Agronomy, 80*(4), 631-634. https://doi.org/10.2134/agronj1988.00021962008000040017x

Hassani F., Zare L. & Khaledi, N. (2019). Evaluation of germination and vigor indices associated with *Fusarum*-infected seeds in pre-basic seeds wheat fields. *Journal of Plant Protection Research, 29*(1)*,* 69-85. https://doi.org/10.24425/jppr.2019.126037

Ihsanullah A.J., Taj F.H., Amanulla J. & Ahmad I. (2002). Effect of sowing dates on yield and yield components of Mashbean varieties. *Asian Journal of Plant Science, 1*(6)*,* 622-624. https://doi.org/10.3923/ajps.2002.622.624

ISTA (International Seed Testing Association) (2013). The germination test. In: *International Rules for Seed Testing.* Bassersdorf, Switzerland, 56 pp. https://doi.org/10.15258/istarules.2017.05

Kildisheva O.A., Erickson T.E., Madsen M.D., Nixon K.W. & Merritt D.J. (2019). Seed germination and dormancy traits of forbs and shrubs important for restoration of North American dryland ecosystems. *Plant Biology, 21,* 458-469. https://doi.org/10.1111/plb.12892

Liebenberg A.J. (2010). *Drybean production*. Department of Agriculture, Republic of South Africa. https://www.nda.agric.za/docs/drybean/drybean.htm

Louwaars N.P. & Manicad, G. (2022). Seeds Systems Resilience – An Overview. *Seeds, 1(4): 340-356* https://doi.org/10.3390/seeds1040028

Priyanka N., Geetha N., Mansour G. & Perumal, V. (2019). Role of engineered zinc and copper oxide nanoparticles in promoting plant growth and yield: Present status and future prospects. *Advances in Phytonanotechnology,* 183-201. https://doi.org/10.1016/B978-0-12-815322-2.00007-9

Rahman M., Hossain M., & Bell R. (2011). Plant density effects on growth, yield and yield components of two soybean varieties under equidistant planting arrangement. *Asian Journal of Plant Science, 10*(5)*,* 278-286. https://doi.org/10.3923/ajps.2011.278.286

Rajendra Prasad, S. (2023). Testing Seed for Quality. In: Dadlani, M., Yadava, D.K. (eds) Seed *Science and Technology*.

Springer, Singapore. https://doi.org/10.1007/978-981-19-5888-5_13

Sako Y., McDonald M.B., Fujimura K., Evans A.F. & Bennett, M.A. (2001). A system for automated seed vigour assessment. *Seed Science and Technology 29(3):625-636.* https://www.researchgate.net/publication/279571809_A_system_for_automated_seed_vigour_assessment

Singh, M., Bisht, I.S. & Dutta, M. eds. (2014). *Broadening the genetic base of grain legumes*. Springer. https://doi.org/10.1007/978-81-322-2023-7

Taiz L., Zeiger E., Møller I.M. & Murphy A. (2018). *Fundamentals of Plant Physiology*. ISBN: 9781605357904. 561 pp. Oxford University Press.

Takahashi F., Suzuki T., Osakabe Y., Betsuyaku S., Kondo Y., & Dohmae N. (2018). A small peptide modulates stomatal control via abscisic acid in long-distance signaling. *Nature, 556(*7700), 235. https://doi.org/10.1038/s41586-018-0009-2

Thanuja P.C., Sadashiv N. & Shashikala S.K. (2019). Effect of pre-sowing seed treatments on seed germination and seedling growth in Rakta Chandana (*Pterocarpus santalinus* L.): An endangered medicinal plant. *International Journal of Chemical Studies, 7*(3), 1577-1580.