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Tool for determining levels and classifying; host plant resistance, tolerance to stress, vigour and pathogen virulence in plants

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ABSTRACT

The global food security and plant resources levels are continuously under threat from climate change, environmental pollution, population pressure, co-evolving plant pests and pathogens. Currently, scientists across the world are in pursuit of plant genotypes that can be resilient in growth and development amidst these stresses to enable survival of humans in the changing times. Therefore, to effectively select plants that have known and favorable resistance or tolerance levels against these stresses, a reliable tool that can determine quantitatively the levels of these good traits during evaluation and selection is necessary in plant protection. However, the lack of such a tool has left scientist to rely on qualitative approaches that are subjective and prone to significant errors. Hence, the aim of this study was to develop an algorithm based tool that can quantitatively estimate selected desirable traits. The research question guiding the study was; how will the estimated quantitative levels of selected desirable traits by the algorithm compare with known properties of selected plant varieties? This is because quantitative strategies of estimation are usually objective and consistent in producing outputs. Therefore, this article presents a software tool known as the OMATEC-HTVP calculator of host plant resistance, tolerance, vigour and pathogen virulence levels. The tool calculates the percentage levels of selected variables and is designed to classify them. The tool works by integrating any six parameters of a crop, plant or hybrid under evaluation using its infected,stressed or improved (modified) treatment relative to their uninfected,unstressed or parent check treatment respectively. The approach uses an infused modified five step omatec host plant resistance and pathogen virulence algorithm. The calculator is designed in Microsoft® Excel 2010 and is availed for training and research through this article's link as supplementary file. After, development the tool was used on test data of two plant varieties of napier grass (*Pennisetum purpureum*) infected by *Ustilago kamerunensis* pathogen: Clone 13 variety had a host plant resistance and pathogen virulence/damage levels of 9.8% and 90.2% respectively. The coefficient of variation of the data used of Clone 13 variety was 12.4%, whereas the classification of the calculated variables of the variety was low resistance and very high virulence/damage levels. On the other hand, Kakamega 2 host plant resistance was 59.1% and pathogen virulence/damage was 40.9%. The coefficient of variation of the variety's data used in the calculator was 8.4%, with the variables classification of high resistance and

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moderate virulence/damage levels. In conclusion, the tool's outputs using the test data was consistent with the general characteristics of the varieties. Further, the mathematical logic used to develop it appears clear based on principle of relative performance of biological systems and the unique property of logarithmic functions to assign similar output values in evaluation of relative performances of treatments that increase by a certain magnitude, without discriminating the units used in measuring various parameters.

Introduction

The World's food security level especially from plants is continuously under threat from the changing climate, increased environmental pollution due to civilization and co-evolving plant pests and pathogens that are highly severe [1,2]. These scenarios have constantly pushed scientists across the globe to diligently seek solutions to this problems by conducting selection experiments for superior and novel plant varieties, cultivars to stocks that are resistant and tolerant to these stressors [3]. The process of selection has been characterized largely by qualitative disease or stress scoring approaches that are prone to huge errors and are highly subjective [4–6]. The consequences of these state of affairs has been selection of plants based on unreliable data which leads to poorly selected plant germplasms that end up breaking down their resistance or tolerance qualities [2,7-9]. Further, to manage co-evolution of pests and pathogens to more virulent strains, knowing the level of resistance subjected to the pest or pathogen is paramount in plant pathology [1,3,10,11]. This is because previous studies have reported that high resistance levels tend to exert high selection pressure on pathogens leading to high rates of co-evolution [1,12]. The need to determine quantities of vigour, host plant resistance and tolerance levels against stressors using classical approaches of plant studies has been attempted by scientists since the onset of the 20th century [10,13,14]. The interest of many plant scientists in this approach of classical analysis using mathematical functions has magnified the desire to realize this dream [8,15].

This article presents a calculator developed in Microsoft® Excel 2010, known as the OMATEC calculator of host plant resistance/tolerance, hybrid/modification vigour and pathogen virulence. Further, the calculator is programmed to categorize the determined variables for ease of interpretation and synthesis. The presented tool works by a modified approach of integrating the mean of six parameters using relativity mathematical functions from infected/stressed plants' treatments and analyses them against the mean of the same six parameters of the uninfected/unstressed (control) treatment in an experiment [6]. The transition from evaluating a single parameter to integrating multiple parameters improves system accuracy and holistic evaluation, leading to a reliable output that can estimate the reality about a particular performance [15–17]. The research strategy used in this study is motivated by Hunt et al. [15], who created an excel-based tool to aid in the analysis of certain plant growth parameters. Therefore, to effectively select plants that exhibit known and favorable resistance or tolerance levels against these stresses, this study developed a tool that can quantify the levels of good traits during evaluation and selection as a supplement to screening experiments in plant health, breeding and protection. The research question guiding the study was; how will the estimated quantitative levels of selected desirable traits by the algorithm compare with the known properties of selected plant varieties?

Materials and methods

Study approach

The study strategy involved the design of a five step algorithm and its infusion in a modified Microsoft® excel 2010 platform to develop a calculator that quantitatively determines, the host plant resistance, tolerance, vigour and pathogen virulence levels. The calculator was inspired by Hunt et al. [15] modern plant analysis software tool, which was also based in Excel.

The designed algorithm

The five steps algorithm is modified from the Omatec host plant resistance and pathogen virulence algorithm [6]. Where the modification involves the determination of natural logarithmic divergence index (DI), which estimates the efficiency in performance of the infected plant treatments relative to its control (uninfected treatment). The function involved integrates six parameters measured from the treatments to increase the accuracy of estimation [16]. Further, this is a modification of Parry [10] and Omayio [6] which used one parameter and three parameters respectively to estimate relative efficacy levels in performance using natural logarithms. In addition, the algorithm used in this calculator introduces a function that accurately gives the determined divergence indices magnitude between a scale of 0% and 100% that estimates resistance and pathogen

virulence levels. The logarithmic indexing approach has been used extensively in evaluation of biological systems as per Causton and Venus [13], Parry [10], Hunt et al. [15], Omayio [11] and Omayio et al. [17]. The advantage of using logarithms is in its ability to integrate various parameters of different units without a huge variance and giving relative performance regardless of the units of the parameters involved. Hence, generating relative efficacy indices that can estimate the efficiency of a biological system in performance [6,10,13,15].

The five steps modified algorithm which was infused into the calculator is as follows;

Step one; Determination of the divergence index of a plant (DI) and input data's coefficient of variation

The function below was modified from Parry [10] and Omayio [6] to integrate the individual means of six parameters measured from a plant's infected and uninfected treatments respectively to determine relative efficacy levels (divergence index of the infected from the control) in performance using natural logarithms as follows;

$$Divergence\ Index\ (DI) = (LN(P1i \times P2i \times P3i \times P4i \times P5i \times P6i)) - (LN(P1u \times P2u \times P3u \times P4u \times P5u \times P6u)) \quad (1)$$

Where; P1i, P2i, P3i, P4i, P5i and P6i represent the means of the six parameters measured from the infected or diseased plants' treatments under evaluation. Then, P1u, P2u, P3u, P4u, P5u and P6u represent the means of the same six parameters as above measured from the uninfected (control) or non-diseased plants' treatments under evaluation simultaneously in an experiment.

Also, at this stage the input data's coefficient of variation was infused into the tool to enable one estimate how reliable and stable the outputs determined by this calculator are likely to be as demonstrated;

$$Coefficient\ of\ variation = \left(\frac{\left(\frac{S.D1i}{P1i} + \frac{S.D2i}{P2i} + \frac{S.D3i}{P3i} + \frac{S.D4i}{P4i} + \frac{S.D5i}{P5i} + \frac{S.D6i}{P6i} + \frac{S.D1u}{P1u} + \frac{S.D2u}{P2u} + \frac{S.D3u}{P3u} + \frac{S.D4u}{P4u} + \frac{S.D5u}{P5u} + \frac{S.D6u}{P6u} \right)}{12} \right) \times 100\% \quad (2)$$

Where; S.D1i, S.D2i, S.D3i, S.D4i, S.D5i and S.D6i represent the respective standard deviations of the individual means P1i, P2i, P3i, P4i, P5i and P6i of the six parameters measured from the infected or diseased plants' treatments under evaluation. Whereas, S.D1u, S.D2u, S.D3u, S.D4u, S.D5u and S.D6u represents the respective standard deviations of the individual means P1u, P2u, P3u, P4u, P5u and P6u of the same six parameters as above but measured from the uninfected (control) or non-diseased plants' treatments under evaluation simultaneously in an experiment.

Step two; determination of the potential factor (PotF)

This potential factor was the antilogarithmic value of the positive value of divergence index determined in step one. Since, the negative value in the answer indicates the decline in performance of the treatment from the control [10]. This potential factor is an absolute value that enables estimation of the power in decline in plant performance due to the disease damage since percentages are equally absolute values [16,18].

$$Potential\ Factor\ (PotF) = e^{(DI \times -1)} \quad (3)$$

Where; DI is the divergence index determined from Equation 1 multiplied by negative one (-1) to change it into a positive form. Since, the negative indicates decline in performance due to disease damage as per Parry [10]. Hence, the multiplication to eliminate the negative and remain with a positive value whose antilog is determined by raising the natural constant (e) to that power as demonstrated above (Equation 3).

Step three; determination of the percentage level equivalent of the divergence index

This percentage equivalent of divergence index is the estimator of the host plant resistance levels of the plant and difference of the same from 100% is the levels of damage due to the pathogen involved.

$$\text{Percentage equivalent of divergence index (Host plant resistance)} = \frac{100\%}{Potential\ Factor(PotF)} \quad (4)$$

Where; the potential factor is the value determined in step two above of the modified algorithm. The 100% reflects the maximum levels of host plant resistance, based on the assumption that when a plant is not diseased the maximum potential/efficiency of resistance it exhibits is 100%. When infected by a disease this potential reduces to a level where it cannot reduce anymore due to resistance in the plant against the pathogen. And this is the host plant resistance levels. The levels of decline in percentage estimate the damage levels due to pathogen virulence.

Illustration on the rationale behind the determination of host plant resistance (Percentage equivalent of divergence index). The following one parameter illustration is used to demonstrate the determination of host plant resistance percentage. Assume in an experiment the control (uninfected plant) of a certain plant species mean biomass levels is **100 grams** after a specified period of experimentation. The mean biomass levels produced by the diseased (infected treatment) is **50 grams** after the specified period.

Table 1
Showing the classification levels of host plant resistance/tolerance as infused in the calculator.

Host plant resistance/Tolerance levels	Classification
0% - 24%	Low-Resistance/Tolerance
25% - 49%	Moderate-Resistance/Tolerance
50% -74%	High-Resistance/Tolerance
75% -100%	Very High-Resistance/Tolerance

Table 2
Showing the classification levels of pathogen virulence as infused in the calculator.

Pathogen virulence levels	Classification
0% - 24%	Low -Virulence/Severity/Damage Levels
25% - 49%	Moderate -Virulence/Severity/Damage Levels
50%-74%	High-Virulence/Severity/Damage Levels
75% - 100%	Very High -Virulence/Severity/Damage Levels

Therefore, using natural logarithms divergence index (DI) is calculated by taking natural logarithm of the parameter levels of the infected treatment minus the natural logarithm of the same parameter levels of the control (uninfected treatment) as shown below;

$$LN(50) - LN(100) = -0.69315 \quad \text{(Illustration 1)}$$

The negative of the index (-0.69315) indicates decline in performance attributed to the infection. Thus, to determine the percentage equivalent of such a performance, the antilog of the positive value (0.69315) is determined ($e^{0.69315} = 2$) which is 2. The performance levels of the infected plant since it had reduced based on the expected maximum of 100% resistance; we take the 100% divide by the absolute value 2 which will give us 50% which is the host plant resistance levels. This means the level of host plant resistance reduced from the expected 100% maximum performance due to pathogen damage to 50%. The levels of damage due to virulence from the pathogen is then determined by subtracting host plant resistance levels from the 100% maximum as follows (100%-50%) = 50% virulence levels. This explains how the logarithmic indices are used to derive these variables of plant pathology during screening as infused in the calculator.

$$LN(100) - LN(100) = 0 \quad \text{(Illustration 2)}$$

In Illustration 2; assume the mean performances of the control (uninfected plant) and diseased (infected treatment) of a certain plant species are equal; that is mean biomass levels of **100 grams** each, after a specified period of experimentation. Therefore, using natural logarithms divergence index (DI) is calculated by taking natural logarithm of the parameter levels of the infected treatment minus the natural logarithm of the same parameter levels of the control (uninfected treatment) as shown below;

The zero (0) divergence index means they had an equal performance. Thus, to determine the percentage equivalent of such a performance, the antilog of the value (0) is determined ($e^0 = 1$) which is 1. If this scenario arises it means the plant was not damaged by the pathogen. Therefore, as shown in Illustration 1 above; to determine host plant resistance we take the 100% possible maximum divide by the absolute value 1 which will give us 100% which is the host plant resistance levels. The levels of damage due to virulence from the pathogen is then determined by subtracting host plant resistance levels from the 100% maximum as follows (100%-100%) = 0% virulence levels. The 0% means the pathogen did not damage or injure the plant.

Step four; classification of host plant resistance and pathogen virulence levels

The calculator was designed to classify the levels of host plant resistance and pathogen virulence levels as modified from Keane[19], Wamalwa et al. [20] and Omayio [6] as demonstrated in Table 1;

This is because host plant resistance is a continuum which ranges from highly susceptible (low resistance on the lower end and very high resistance/immune on the higher end [19–21]. Therefore, the four quarters of the scale between 0% to 100% led to the classification.

The pathogen virulence was classified using the modified approach above since virulence of above 50% is considered significant as per Parry [10], the classification when infused in the calculator was as shown in Table 2;

Step five; Determination of the vigour levels of the infected, hybrid or an improved plant

This variable can be determined for the infected plant besides enabling the genetic scientists and plant breeders who may want to use the calculator to determine hybrid vigour or heterosis levels (enhanced performance over both parents) of a progeny relative to commercial check variety, better parent or mid-parent [22]. Further, a modified plant's superior levels in performance or vigour relative to its parent's performance or control can be determined [23]. The function used was

Table 3
Showing the classification levels of vigour as infused in the calculator.

Vigour levels	Classification
Below 24%	Low- Vigour
25% - 49%	Moderate -Vigour
50% - 74%	High- Vigour
Above 75%	Very High- Vigour

modified from the approach of relativity by Phundan [24]. Here mean of six parameters were integrated into the function which will be measured from a either the infected, hybrid, or modified plant depending on what one wants to calculate, whose performance will be evaluated relative the mean of the same six parameters of the parent or control plant. This modifies the traditional function by introducing analysis of more parameters (six parameters) unlike the conventional (one parameter) leading to a comprehensive evaluation [22,24]. The infused function is demonstrated below;

$$IPRPL(\%) = \left(\frac{\left(\left(\frac{P1i}{(P1i+P1u)}\right) + \left(\frac{P2i}{(P2i+P2u)}\right) + \left(\frac{P3i}{(P3i+P3u)}\right) + \left(\frac{P4i}{(P4i+P4u)}\right) + \left(\frac{P5i}{(P5i+P5u)}\right) + \left(\frac{P6i}{(P6i+P6u)}\right)\right)}{6} \right) \times 100\% \quad (5)$$

$$UPRPL(\%) = \left(\frac{\left(\left(\frac{P1u}{(P1i+P1u)}\right) + \left(\frac{P2u}{(P2i+P2u)}\right) + \left(\frac{P3u}{(P3i+P3u)}\right) + \left(\frac{P4u}{(P4i+P4u)}\right) + \left(\frac{P5u}{(P5i+P5u)}\right) + \left(\frac{P6u}{(P6i+P6u)}\right)\right)}{6} \right) \times 100\% \quad (6)$$

$$Vigour\ levels\ (\%) = \left(\frac{(IPRPL(\%) - UPRPL(\%))}{UPRPL(\%)} \right) \times 100\% \quad (7)$$

Where; IPRPL(%) is the infected plants relative performance levels in percentage, however, when calculating hybrid vigour of an improved/modified plant or progeny this abbreviation can be modified and referred to as hybrid or modified plant relative performance levels in percentage (HPRPL or MPRPL (%)). Then, UPRPL(%) is the uninfected (control) plants relative performance levels in percentage, however, when calculating hybrid vigour of an improved/modified plant or progeny this abbreviation can be modified and be referred to as Parent or control plant relative performance levels in percentage (PPRPL or CPRPL (%)). The division of the functions by the value (6) is to determine the average of relative performance before multiplying by 100% to determine percentage, since six parameters have been introduced to modify the function to give a comprehensive multivariable analysis of the final output.

The classification of the vigour outputs in the calculator was modified and infused as per Singh [22] as demonstrated in Table 3;

Test data for the calculator from selected two varieties of napier grass

Test data for the calculator of two Napier grass (*Pennisetum purpureum*) varieties was provided by ICIPE (International Centre for Insect Physiology and Ecology) -Mbita, Kenya to be used to test this calculator ability to predict quantitatively the host plant resistance and pathogen virulence levels of napier head smut disease pathogen called *Ustilago kamerunensis* as demonstrated in the Table 4 below. The data involved napier grasss (*Pennisetum purpureum*) varieties Clone 13 and Kakamega 2 which are classified as susceptible and resistant respectively to head smut disease [25]. The varieties had been evaluated under glasshouse conditions between April, 2018 and March, 2019 to limit other intervening environmental variables.

The test data captures the mean ± standard deviation of the respective six parameters. The treatments had been replicated ten times under glasshouse conditions at the International Centre for Insect Physiology and Ecology-Mbita, Kenya. The data was used to test the calculator in determination of the various outputs.

The above data was input into the calculator to determine the host plant resistance, pathogen virulence levels and their respective classification as will be demonstrated in the results section. The assigning of parameter numbers 1, 2, 3 as shown in Table 4 is done randomly by the researcher. That is any of the six parameters can take any number to aid in maintaining the order of entry of the measurements in the calculator as is demonstrated in Fig. 1.

The OMATEC-HTVP calculator's structural design and layout

The designed calculator is structured in the following manner; the parameters wordings on the left hand side of the calculator as shown in Fig. 1, are colored to ensure consistence and uniformity in entry as guided by ones labeling of parameters as demonstrated in Table 4 of the test data. For instance from the Table 4; the parameter 1 is the biomass levels of a variety's treatments. In the calculator the slot labeled in red as parameter 1 below the words (INPUT 1), is where the mean of biomass for the infected plant will be entered and the adjacent slot to the right is where its standard deviation is

Table 4
Test data of two varieties (Clone 13 & Kakamega 2) mean performances in six parameters across two trials of 24 weeks each of growth under *Ustilago kamerunensis* infection and their uninfected controls.

Parameters Involved	Clone 13 variety		Kakamega 2 variety	
	Infected treatment	Uninfected treatment(Control)	Infected treatment	Uninfected treatment(Control)
Parameter 1 (Biomass in grams)	255.46 ± 12.16	362.52 ± 7.18	324.83 ± 14.24	390.54 ± 9.11
Parameter 2 (Plant height in cm)	110.59 ± 3.02	163.65 ± 8.04	147.93 ± 6.15	155.65 ± 4.08
Parameter 3 (Chlorophyll in SPAD units)	30.90 ± 0.87	45.52 ± 3.01	45.83 ± 3.26	48.40 ± 1.07
Parameter 4 (Leaf Number)	23.82 ± 6.14	35.54 ± 3.21	29.55 ± 2.19	30.80 ± 3.14
Parameter 5 (Leaves weight in grams)	29.88 ± 10.18	40.92 ± 12.04	38.45 ± 10.30	42.99 ± 8.07
Parameter 6 (Leaf area in cm^2)	60.77 ± 8.18	98.39 ± 13.02	100.89 ± 7.12	109.65 ± 9.05

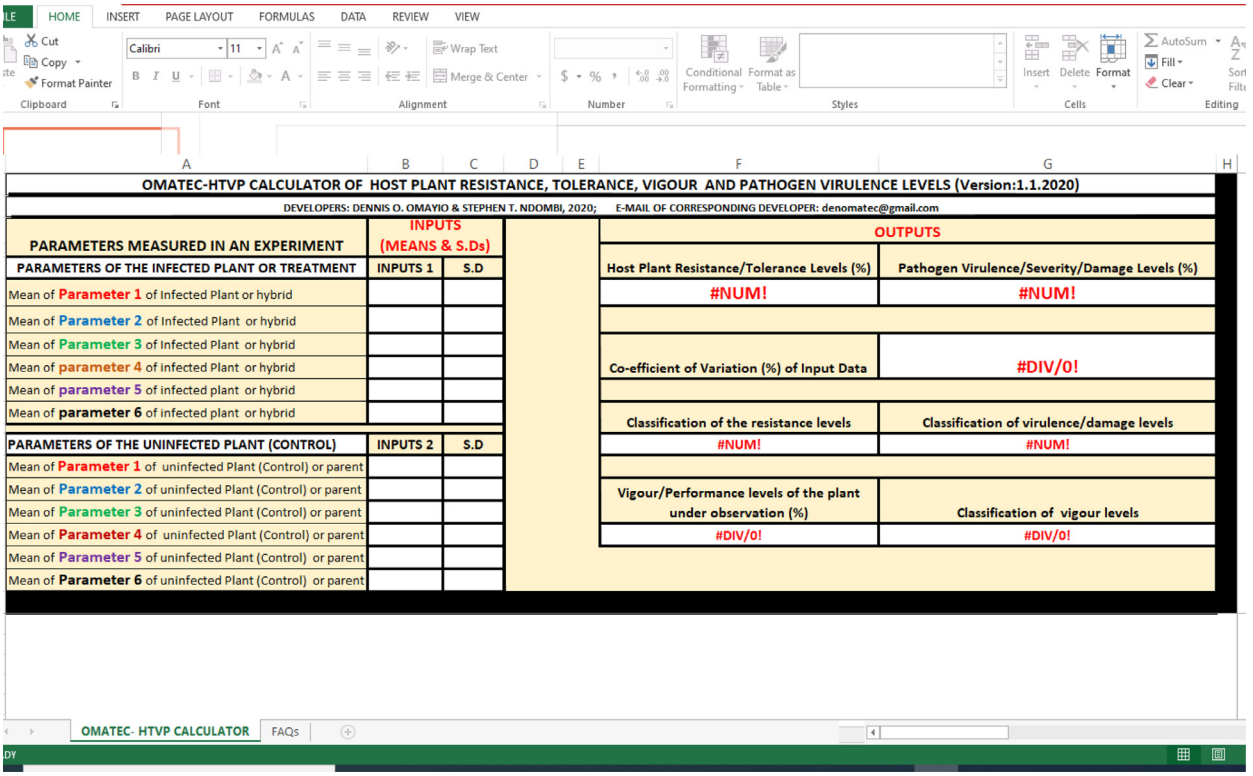
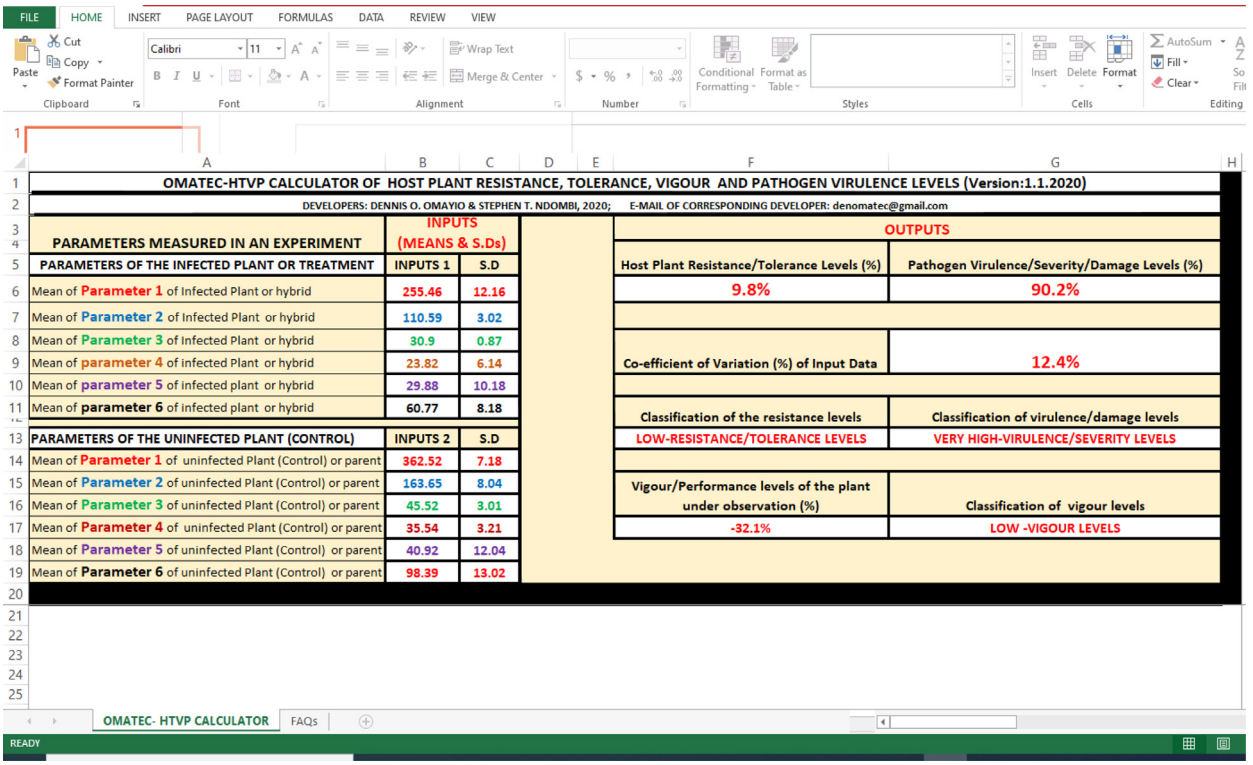


Fig. 1. The architecture of the OMATEC-HTVP calculator structure shows the six input slots which are colored white below the words (INPUTS 1) for the means of the six parameters measured from the infected treatment or hybrid if host plant resistance and vigour are to be calculated respectively. Whereas, the six input slots which are colored white below the words (INPUTS 2) is for the means of the six parameters measured from the uninfected treatment or parent check if host plant resistance and vigour are to be calculated respectively. These are the only active cells where data can be entered in the calculator as per design. In case the parameters means have their standard deviations (S.D) captured as per test data in Table 4; these measures of dispersion have their respective slots shown next to the mean inputs to enable estimation of the means average coefficient of variation levels introduced by the respective parameters' into the final calculations. When no data is entered in the input slots, this is how the inactive mode of the calculator looks like, until a suitable matrix of data is entered to activate the computation.

entered. Whereas, the mean biomass levels of the uninfected (control) will be entered in the red labeled parameter 1 slot just below the words (INPUT 2), with its standard deviation entered on the adjacent slot to the right hand side. Thus, the other parameters will be entered in their specific slots depending on their numbering as highlighted in Table 4 in such a uniform manner for a reliable output and classification.



OMATEC-HTVP CALCULATOR OF HOST PLANT RESISTANCE, TOLERANCE, VIGOUR AND PATHOGEN VIRULENCE LEVELS (Version:1.1.2020)

DEVELOPERS: DENNIS O. OMAYIO & STEPHEN T. NDOMBI, 2020; E-MAIL OF CORRESPONDING DEVELOPER: denomatec@gmail.com

PARAMETERS MEASURED IN AN EXPERIMENT	INPUTS (MEANS & S.Ds)	
PARAMETERS OF THE INFECTED PLANT OR TREATMENT	INPUTS 1	S.D
Mean of Parameter 1 of Infected Plant or hybrid	255.46	12.16
Mean of Parameter 2 of Infected Plant or hybrid	110.59	3.02
Mean of Parameter 3 of Infected Plant or hybrid	30.9	0.87
Mean of parameter 4 of infected Plant or hybrid	23.82	6.14
Mean of parameter 5 of infected plant or hybrid	29.88	10.18
Mean of parameter 6 of infected plant or hybrid	60.77	8.18
PARAMETERS OF THE UNINFECTED PLANT (CONTROL)	INPUTS 2	S.D
Mean of Parameter 1 of uninfected Plant (Control) or parent	362.52	7.18
Mean of Parameter 2 of uninfected Plant (Control) or parent	163.65	8.04
Mean of Parameter 3 of uninfected Plant (Control) or parent	45.52	3.01
Mean of Parameter 4 of uninfected Plant (Control) or parent	35.54	3.21
Mean of Parameter 5 of uninfected Plant (Control) or parent	40.92	12.04
Mean of Parameter 6 of uninfected Plant (Control) or parent	98.39	13.02

OUTPUTS	
Host Plant Resistance/Tolerance Levels (%)	Pathogen Virulence/Severity/Damage Levels (%)
9.8%	90.2%
Co-efficient of Variation (%) of Input Data	12.4%
Classification of the resistance levels	Classification of virulence/damage levels
LOW-RESISTANCE/TOLERANCE LEVELS	VERY HIGH-VIRULENCE/SEVERITY LEVELS
Vigour/Performance levels of the plant under observation (%)	Classification of vigour levels
-32.1%	LOW -VIGOUR LEVELS

Fig. 2. The results by the calculator upon entry of the means of the various parameters of Clone 13 variety in their right slots on the left hand side of the calculator as demonstrated. The Clone 13 host plant resistance was calculated at 9.8% with the pathogen virulence/damage levels estimated at 90.2% as shown on the outputs section on the right hand side of the calculator.

Results

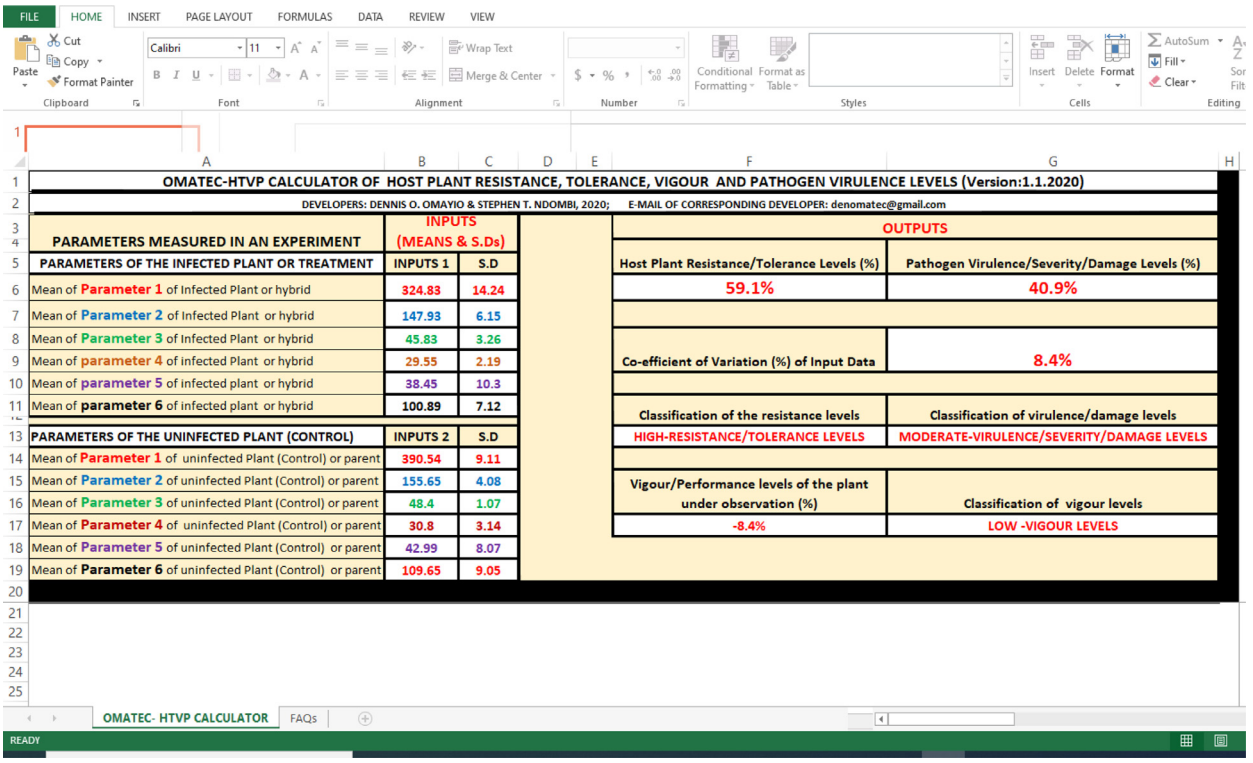
Inputs versus the calculator's outputs

The experimental data from Table 4 for clone 13 was input into the slots of the calculator and the output is shown in the screenshot captured as Fig. 2. The Clone 13 napier grass variety had host plant resistance levels of 9.8% whose classification was low resistance/tolerance levels (Fig. 2). The pathogen damage levels of the variety were estimated at 90.2%, with a classification of very high virulence/severity/damage levels (Fig. 2). The vigour which is measured by default due to the overlapping nature of the functions in the calculator was estimated at -32.1% with a classification of low vigour. The negative indicates a decline in vigour which makes sense when comparing a hybrid or modified plant treatments relative to their mid-parent, commercial variety or better parent's treatments as a control in plant improvement or breeding experiments. The estimated coefficient of variation introduced into the calculations due to the standard deviations of the respective means was estimated at 12.4% which is significantly low, making the outputs reliable (Fig. 2).

The other napier grass variety Kakamega 2 had host plant resistance levels of 59.1% whose classification was high resistance/tolerance levels (Fig. 3). The pathogen damage levels of the variety were estimated at 40.9%, with a classification of moderate virulence/severity/damage levels. The vigour which is measured by default due to the overlapping nature of the functions in the calculator was estimated at -8.4% with a classification of low vigour levels (Fig. 3). The negative indicates a decline in vigour which makes sense when comparing a hybrid or modified plant treatments relative to their mid-parent, commercial variety or better parent's treatments in plant improvement or breeding experiments. The estimated coefficient of variation introduced into the calculations due to the measures of dispersion (standard deviations) of the respective means was estimated at 8.4% which is significantly low, making the outputs reliable (Fig. 3).

Discussion

The calculator demonstrated consistency in integrating the data input values and generation of an output that can be relied on as demonstrated on Fig. 2 and Fig. 3, which is basically the properties of a good scientific tool [15,26,27]. In this study quantitative levels of host plant resistance and pathogen virulence were determined solving the challenge of over relying on qualitative approaches like visual scoring for resistance, which are error prone and characterized by lots of subjectivity during experiments [4–6]. The OMATEC-HTVP calculator effectively determined and validated the low and high



OMATEC-HTVP CALCULATOR OF HOST PLANT RESISTANCE, TOLERANCE, VIGOUR AND PATHOGEN VIRULENCE LEVELS (Version:1.1.2020)

DEVELOPERS: DENNIS O. OMAYIO & STEPHEN T. NDOMBI, 2020; E-MAIL OF CORRESPONDING DEVELOPER: denomatec@gmail.com

PARAMETERS MEASURED IN AN EXPERIMENT	INPUTS (MEANS & S.Ds)	
PARAMETERS OF THE INFECTED PLANT OR TREATMENT	INPUTS 1	S.D
Mean of Parameter 1 of Infected Plant or hybrid	324.83	14.24
Mean of Parameter 2 of Infected Plant or hybrid	147.93	6.15
Mean of Parameter 3 of Infected Plant or hybrid	45.83	3.26
Mean of parameter 4 of infected Plant or hybrid	29.55	2.19
Mean of parameter 5 of infected plant or hybrid	38.45	10.3
Mean of parameter 6 of infected plant or hybrid	100.89	7.12
PARAMETERS OF THE UNINFECTED PLANT (CONTROL)	INPUTS 2	S.D
Mean of Parameter 1 of uninfected Plant (Control) or parent	390.54	9.11
Mean of Parameter 2 of uninfected Plant (Control) or parent	155.65	4.08
Mean of Parameter 3 of uninfected Plant (Control) or parent	48.4	1.07
Mean of Parameter 4 of uninfected Plant (Control) or parent	30.8	3.14
Mean of Parameter 5 of uninfected Plant (Control) or parent	42.99	8.07
Mean of Parameter 6 of uninfected Plant (Control) or parent	109.65	9.05

OUTPUTS	
Host Plant Resistance/Tolerance Levels (%)	Pathogen Virulence/Severity/Damage Levels (%)
59.1%	40.9%
Co-efficient of Variation (%) of Input Data	8.4%
Classification of the resistance levels	Classification of virulence/damage levels
HIGH-RESISTANCE/TOLERANCE LEVELS	MODERATE-VIRULENCE/SEVERITY/DAMAGE LEVELS
Vigour/Performance levels of the plant under observation (%)	Classification of vigour levels
-8.4%	LOW -VIGOUR LEVELS

Fig. 3. The results by the calculator upon entry of the means of the various parameters of Kakamega 2 variety in their right slots on the left hand side of the calculator as demonstrated. The Kakamega 2 host plant resistance was calculated at 59.1% with the pathogen virulence/damage levels estimated at 40.9% as shown on the outputs section on the right hand side of the calculator.

host plant resistance levels present in Clone 13 and Kakamega 2 napier grass varieties respectively (Fig. 2 and Fig. 3). This was based on the test data evaluated from ICIPE-Mbita in Table 4. These results from the calculator's outputs confirm the general disease response characteristics of these two varieties against the head smut disease as per Kabirizi et al. [25].

The head smut pathogen has been reported to significantly damage Clone 13 unlike Kakamega 2 variety which is generally regarded as resistant to the pathogen by the scientific community [28,29]. This has seen its approval by the Kenyan ministry of agriculture for adoption in management of the napier head smut disease by farmers across the country [25,29]. Further, this study's calculator tool validated Clone 13 variety's high damage levels impacted by *Ustilago kamerunensis* pathogen by integrating the provided data in Table 4 that generated a classification of very high virulence/severity/damage levels (Fig. 2). This is very promising especially with heightened screening for high levels of resistance, tolerance and hybrid vigour in plants amidst changing global conditions that threaten the survival of humans [2]. The calculator provides an avenue for objective and uniform quantification of these traits in plants which has been lacking due to reliance on visual scoring approaches customized for respective plants [10]. The scenario of each plant having its own scoring key due to the variations in symptoms has made screening process to be laborious and very subjective due to differences in researchers' abilities to process and analyze plant systems qualitatively [4,5].

Conclusion

The concept used to derive the calculator's algorithm, logically determines the outputs accurately as per the observed characteristics of the test plant varieties' used in validation of its potential as a tool. This is promising as a likely tool that complements the screening efforts of resistant or tolerant plant germplasms in efforts to secure the World's food systems amidst harsh and changing environmental stressors.

Recommendations

The measured parameters of the infected and uninfected plant treatments should focus on those significantly affected by the disease under study to accurately determine the host plant resistance and the other variables. Further, the replicates of the plant treatments which provide the means of the parameters entered in the inputs of the calculator should be more; if possible six and above replicates towards giving a good mean that can estimate resistance well by reducing the standard

deviation or error. This will give a true or near true levels of the calculated outputs. This is possible because the more the replicates the higher the reliability of the data.

FAQs (Frequently Asked Questions; about the calculator's capabilities)

What are the other variables that can be calculated by the Omatec- htvp calculator of host plant resistance/tolerance and pathogen virulence levels?

The calculator can determine tolerance levels of a plant species, cultivar or variety etc.; against a stressor, where in the inputs 1 active section, the measured six parameters of the stressed plant are entered in the correct order using the colours of the parameters as a guide to avoid mixing up the inputs. Then the parameters of their controls (unstressed) are entered in the inputs 2 active section of the calculator in the right sequence and order using the parameter colours to avoid mixing up the entry sequence to produce the correct and reliable output.

What are the other variables that can be determined by the vigour levels output?

The OMATEC-HTVP calculator output section of vigour can be used to determine hybrid vigour or the impact of modification of a plant species, variety or cultivar relative to its control that is unmodified treatments by placing any six parameters measured of the respective treatments in the correct input 1 and 2 slots in the calculator. This will determine the relative performance and quantify it appropriately. The modification of a plant species can be anything done to a plant ranging from aspects like; genetically engineered plant being compared to a non-engineered ones, another modification can be a plant whose chromosomes have been manipulated like in polyploidization, or the one supplied by some nutrients to determine how it enhances vigour, physical modification etc.

Does it matter what units are used for the different six parameters?

The units used to measure the respective parameters of the treatment with infection or particular stress must be consistent with the units of the same measured parameter of its control treatment. E.g. If plant height was measured in centimeters in the infected/stressed treatment the uninfected/control treatment should be measured in centimeters too e.t.c.

What if some parameters contain missing values of the six required in the inputs section of the calculator?

The calculator only works and gives a reliable output when the respective six parameters of the infected and uninfected treatments are entered in the right order/sequence and consistency using the colours of the various parameters' as a guide to limit mixing of the individual parameters' means in the wrong slots of the calculator.

Can pathogen virulence/damage levels be used as an estimation of severity?

Yes the high the virulence, the high the severity of a pathogen. Therefore, one can use this ouput of host plant resistance calculator as a measure of severity levels of a pathogen in question against a certain plant germplasm, variety, species, cultivar etc., under evaluation.

What is the meaning of DI, PotF, IPRPL, UPRPL, OMATEC and HTVP?

DI; abbreviation for "divergence index", which is the magnitude of variation of the infected treatment from the control (uninfected treatment) as a natural logarithmic index. PotF; abbreviation for "potential factor", which is an absolute number that represents the power of the natural logarithmic index of divergence determined in the calculations. It is this number that is used to establish the magnitude in percentage of host plant resistance between a scale of 0% to 100%. IPRPL; abbreviation for " infected plant relative performance levels" this is the performance levels of infected treatment relative to the control (uninfected) in percentage used a key variable in determination of vigour. UPRPL; abbreviation for "uninfected plant relative performance levels" this is the performance levels of uninfected treatment (control) relative to the infected treatments' in percentage used as a key variable in determination of vigour. OMATEC is acronym for Omayio technologies in acknowledgement of the main developer and HTVP stands for "Host plant resistance-Tolerance-Vigour-Pathogen virulence" to distinguish this version from other calculators under development.

What are the assumptions under which the calculator operates?

The calculator operates under the following assumptions; (1.) the maximum levels of host plant resistance/tolerance in a plant when not infected/stressed by any pathogen is 100%. And these levels decline towards 0% depending on the pathogen's virulence/damage or severity levels. If a pathogen is highly virulent/injurious the resistance will decline from 100% towards zero significantly. (2.) Further, the reason why some pathogens don't affect a plant in any way is because they are non-hosts or they are not a suitable host. Hence, exhibit 100% immunity against such pathogens. (3.) Another, assumption is host plant resistance and tolerance levels can be measured using the same scale of measure. (4.) The vigour of an infected plant reduces from 0% towards negative terms depending on magnitude of infection, since the control also has 0% vigour. Hence, the reason why this output can be used to estimate levels of hybrid vigour, modification of a treatment etc.

What is the source of the inputs for the calculator for it to give a desired output?

The inputs are means of any six parameters measured in an experiment of an infected/stressed treatment of a plant and the means of the same six parameters measured from the control (uninfected) treatments of the plant or crop under evaluation. The reason for the six parameters is to increase the degree of freedom to (5) to increase the reliability levels of the host plant resistance levels' output.

Does the order of inputs entry of the means of the six parameters measured matter in the calculator's input slots?

Yes the order matters since; the calculator is based on relativity concept. The parameters have been coloured to ensure the order of the means of the parameters entered is maintained for an accurate output. Eq. (2,4–7)

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.sciaf.2022.e01218.

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