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Selection of Superior Potato (*Solanum tuberosum* L.) by Combined Stability Analysis for Future Breeding Strategies

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Potato is one of the main agricultural commodities and has high economic value. Yield is a trait that becomes a benchmark for user (industry and farmers) in selecting and developing varieties. The selection of superior newly potato somaclones using combined analysis and sustainability index (SI) is still underreported. This study aimed to identify the effect of genotype by environment (growing season) interactions (GEIs), as well as to select superior potato somaclones. The research was conducted in three years (2020 – 2022) in Lembang, West Java, Indonesia. There were 38 somaclones tested in the field, consisting of 37 gamma ray-derived somaclones and one control genotype. The somaclones originated from commercial varieties Agria, Granola, Repita, and Vega. The field trial used a randomized block design that was repeated three times in each year. GEIs were calculated based on a combined ANOVA. Yield stability was assessed using the combined analysis (parametric and non-parametric), genotype plus genotype by environment interaction (GGE) biplot, and sustainability index (SI). Potato somaclones (G), seasons (E) and GEIs were found to have highly significant influence on yield ($P < 0.01$). According to the combined ANOVA, the GEIs impact accounted for 37.38% of the yield's total sum of squares. Combining parametric and non-parametric measurements, seven somaclones, P3, P4, P5, P6, P8, P9, and P26, were selected. GGE biplot selected five stable somaclones, namely P3, P4, P22, P23, and P26, while SI selected eight high-yielding and stable somaclones, namely P3, P4, P5, P8, P13, P16, P26, and P32. Based on various stability measurements, three genotypes have been identified as the superior somaclones, namely P3, P4 and P26. This analysis can assist in selecting activities to determine superior somaclones.

Key words: non-parametric, parametric, potato, stability, somaclones

Potato is an agricultural commodity that can potentially be developed and has high economic value (Worku *et al.* 2018). It contains high carbohydrates and becomes a major global food commodity. In addition, potato also contains resistant starch, high quality proteins, vitamin C and B6, and potassium (de Haan *et al.* 2019), as well as glycoalkaloids that can inhibit the growth of cancer cells if consumed

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in small portions (Friedman 2015). In cultivation, problems exist, such as varieties susceptible to disease and abiotic stresses, thereby reducing yield production (Abo-Akel *et al.* 2024). A key factor influencing potato yield and productivity is the variety. As such, developing superior potato clones with enhanced disease tolerance can significantly boost both yield and productivity. One of the Indonesian provinces with the largest potato production is West Java. In 2021, West Java contributed 240,482 tons of potato production (Central Boreau of Statistics, 2021). This number makes it the third-highest potato-producing province in Indonesia after East Java (324,338 tons) and Central Java (277,725 tons). Since West Java has a large potato growing area, the yield trials in West Java were considerable.

Yield is a trait that becomes a benchmark for users (industry and farmers) in selecting and developing varieties. Potato yield is essential in overcoming economic, social, and environmental challenges (Koch *et al.* 2020), because the price of potatoes is quite good in the market, which is caused by the high demand. However, potato production in the field is still unable to meet it. In some cases, the yield is greatly influenced by genetics, environment and their interactions (Maulana *et al.* 2022). Specifically, maximum potato yields require the addition of nitrogen fertilisers and also good irrigation management (Andrews *et al.* 2013; Akamis & Caliskan 2023). In addition, potato yields are also very sensitive to humidity (Akamis & Caliskan 2023), so choosing the right location and planting season is very important in large-scale potato production.

Evaluation of potato genotypes in different environments (locations and/or growing seasons) is needed to select superior clones (high-yielding and stable). Selection in these environments, however, is incredibly intricate because of the impact of genotype-environment interactions (GEIs) (Worku *et al*. 2018). Information on GEIs is essential for estimating yield performance in multi-environment or multi-season trials (Wicaksana *et al*. 2022). Unpredictable micro- and macro-environmental factors, including humidity, rainfall, and temperature, led to the emergence of GEIs in multi-environment studies (Maulana *et al*. 2022). According to Worku *et al.* (2018), different growing environments provided different responses to the yield of each potato somaclone tested. The same thing also happened to other crops, such as sweet potatoes (Maulana *et al.* 2022; Solihin *et al.* 2024) and barley (Vaezi *et al.* 2019). Therefore, information on the effect of GEIs on potato yields is important.

Various estimates for determining GEIs and for identifying stable somaclones including graphical, non-parametric, and parametric estimates. Parametric estimates include Wricke ecovalence (Wi^2) (Wricke 1962), linear regression (Eberhart & Russell 1966), Shukla variance ($\sigma^2 i$) (Shukla 1972), coefficient of variation (CVi) (Francis & Kannenberg 1978), GE variance component ($\theta_{(i)}$) (Plaisted 1960), and the mean-variance component (θi) (Plaisted & Peterson 1959). In addition, the non-parametric estimates are as follows: Thennarasu ($NP^{(i)}$) (Thennarasu 1995), nonparametric ($S^{(i)}$) stability model (Nassar & Huhn 1987; Huehn 1990), and Kang rank (Kang 1988). Currently, visual/graphical estimation of genotypic stability has been widely used such as additive main effects and multiplicative interaction (AMMI) (Gauch 2013) and genotype plus genotype by environment interaction (GGE) biplot (Yan & Tinker 2006). In addition, the use of the sustainability index (SI) in selecting stable genotypes has also been widely reported (Tuteja 2006; Filio *et al*. 2022; Maulana *et al*. 2023). The selection of superior genotypes (stable and high yield) in diverse environments using a single stability analysis was considered less precise (Maulana *et al*. 2022; Wicaksana *et al.* 2022). Estimation of combined stability is much more accurate in the selection of high-yielding and stable genotypes (Vaezi *et al.* 2019). Using integrated stability estimations, several researchers have effectively selected the potential genotype (high yield and consistent) in a variety of environments, including barley (Vaezi *et al*. 2019), maize (Wicaksana *et al*. 2022), sweet potato (Maulana *et al*. 2022), and black soybeans (Susanto *et al*. 2023). Conducting testing to develop varieties in various environments and growing seasons is important to determine the adaptability of these varieties.

The selection of superior potato somaclones using sustainability index (SI) and stability analysis is still underreported. This is the first stability study of new potato somaclones using multivariate measurements and sustainability index (SI), which is accurate and effective for choosing high-yielding and stable potato somaclones. Therefore, this study aimed to: 1. identify the somaclones by growing season interactions (GEIs) on potato yield; 2. selecting potato somaclones with high yield and stable in three years using sustainability index (SI) and stability analysis.

MATERIAL AND METHODS

Plant Materials

The genetic materials used consisted of 37 new potato somaclones resulting from gamma ray irradiation of four commercial varieties, namely Agria, Granola, Repita, and Vega, at doses of 10–50 Gy. One commercial variety was commonly grown by farmers in various regions. Namely, Granola was used as the control. Table 1 provides details about the somaclones used in this study.

Experimental design

Field tests were conducted over three years at Vegetable Crops Research Institute in Lembang, West Java, Indonesia, located at coordinates 6°30’49”S 107°36’33”E in 2020 (September-December), 2021 (April-July), and 2022 (February-May). The altitude of the experimental land location is 1,200 meters above sea level (masl). Observations of climatic conditions were carried out every month during the experiment, which are presented in Table 2. A randomized block design was applied in the field experiment and conducted three replications each year. Each experimental plot measures 2×3 m^2. Fertilisation was applied using chicken manure at 15 t/ha, and chemical fertilisers P_2O_5 200 kg/ha, N 200 kg/ha and K_2O 150 kg/ha. Plant

T a b l e 1

Potato somaclones used in experiment

No.	Code	Somaclones	Initial Variety	No.	Code	Genotypes	Initial Variety
1	P1	G-6	Granola	20	P20	R-15	Repita
2	P2	G-7	Granola	21	P21	G-41	Granola
3	P3	G-9	Granola	22	P22	R-18	Repita
4	P4	G-10	Granola	23	P23	R-25	Repita
5	P5	G-12	Granola	24	P24	R-43	Repita
6	P6	G-16	Granola	25	P25	A-26	Agria
7	P7	G-21	Granola	26	P26	V-50	Vega
8	P8	G-22	Granola	27	P27	R-71	Repita
9	P9	G-26	Granola	28	P28	R-78	Repita
10	P10	G-40	Granola	29	P29	A-14	Agria
11	P11	G-47	Granola	30	P30	A-17	Agria
12	P12	G-48	Granola	31	P31	A-22	Agria
13	P13	G-50	Granola	32	P32	A-27	Agria
14	P14	G-51	Granola	33	P33	A-45	Agria
15	P15	R-5	Repita	34	P34	V-3	Vega
16	P16	R-6	Repita	35	P35	V-8	Vega
17	P17	R-8	Repita	36	P36	V-35	Vega
18	P18	R-10	Repita	37	P37	V-47	Vega
19	P19	R-11	Repita	38	P38	Granola	Commercial variety

T a b l e 2

Climate conditions during field trials

Years	2020 (September-December)	2021 (April-July)	2022 (February-May)
Rainfall [mm]			
Minimum	31.00	11.00	27.50
Maximum	389.30	384.40	357.00
Mean	180.29	168.94	202.13
Temperature [^{O}C]			
Minimum	20.62	20.10	23.69
Maximum	26.34	25.30	25.97
Mean	22.51	23.72	25.03
Relative Humidity [%]			
Minimum	84.67	71.57	72.17
Maximum	92.00	88.63	90.03
Mean	88.91	81.24	83.27

maintenance included hoarding, weeding, and disease and pest management, all done to the demands of the individual plants. Harvesting was done when the plants were 100 days old, and 10 days before harvesting, the stems were pruned so that the tuber skin did not peel off when harvested.

Data collection

Tuber yield per plot [kg] is the observed trait at harvest time (100 days after planting) from a 2×3 m^2 plot of each somaclone. The data were converted to t/ha. A digital scale was utilized to weigh each somaclone's yield.

Data analysis

The GEIs were estimated using a combined analysis of variance (ANOVA) on all somaclones tested. The calculation follows the equation:

$$Y_{ijkl} = \mu + G_i + E_j + GE_{ij} + R_{k(j)} + B_{l(k)} + \varepsilon_{ijkl} \qquad (1)$$

where: Y_{ijkl} represents the tuber yield in plot *l* of somaclone *i*, and the tuber yield in year *j* of each replication *k*; μ represent the total average value on tuber yield trait; G_i − influence of somaclone *e*; E_j represent the influence of the year; GE_{ij} represent the influence of somaclone *i* − by − year *j* interactions; $R_{k(j)}$ represents the influence of replicate *k* on year *j*; $B_{l(k)}$ represents the influence of replicate *k* on plot *l*; and ε_{ijkl} represent the influence error of somaclone *i* in plot *l* and replicate *k* of year *j*, respectively.

The stable potato somaclones were identified by utilizing combined stability models (parametric and nonparametric). Linear regressions follow the Eberhart and Russell (1966) method. Potato somaclone will show stable yield conditions if the regression slope (bi) is 1 and the variance deviation (S^2di) is 0. In accordance with Plaisted and Peterson (1959), the mean-variance component (θi) was computed using the following formula:

$$\theta_i = \frac{p}{2(p-1)(q-1)}\sum_{j-1}^{q}(x_{ij} - \bar{X}_{i.} + \bar{X}_{.j})^2 + \frac{SSGE}{2(p-2)(q-1)} \qquad (2)$$

As per Plaisted (1960) calculation, the GE variance component ($\theta_{(i)}$) was:

$$\theta_{(i)} = \frac{-p}{(p-1)(p-2)(q-1)}\sum_{j-1}^{q}(x_{ij} - \bar{X}_{i.} - \bar{X}_{.j} + \bar{X}_{..})^2 + \frac{SSGE}{(p-2)(q-1)} \qquad (3)$$

As per Wricke (1962) calculation, the Wricke's Ecovalence (Wi^2) was:

$$W_i^2 = \sum(X_{ij} - \bar{X}_{i.} - \bar{X}_{.j} + \bar{X}_{..})^2 \qquad (4)$$

As per Shukla (1972) calculation, Shukla's stability variance was:

$$\sigma_i^2 = \left|\frac{p}{(p-2)(q-1)}\right| W_i^2 - \frac{\sum w_i^2}{(p-1)(p-2)(q-1)} \qquad (5)$$

As per Francis and Kannenberg (1978) calculation, the coefficient of variance (CVi) was:

$$CV_i = \frac{SD_g}{\bar{X}} x\ 100 \qquad (6)$$

where: x_{ij} represents the yield of somaclone *i* in year *j*; $\bar{X}_{i.}$ represents the mean yield of somaclone *i*; $\bar{X}_{.j}$ − average yield of year *j*; $\bar{X}_{..}$ represents the mean yield of all somaclones tested; p − the number of potato somaclone; q − the number of years; SDg represents the standard deviation value of a somaclone mean across year.

In accordance with Nassar and Huhn (1987) and Huehn (1990), stability nonparametric ($S^{(i)}$) models were implemented using the formula:

$$S_i^{(1)} = 2\sum_{j}^{n-1}\frac{\sum_{j'=j+1}^{n}\left|r_{ij} - r'_{ij}\right|}{[N(n-1)]} \qquad (7)$$

$$S_i^{(2)} = \frac{\sum_{j=1}^{n}(r_{ij} - \bar{r}_{i.})^2}{(N-1)} \qquad (8)$$

$$S_i^{(3)} = \frac{\sum_{j=1}^{n}(r_{ij} - \bar{r}_{i.})^2}{\bar{r}_i} \qquad (9)$$

$$S_i^{(6)} = \frac{\sum_{j=1}^{n}\left|r_{ij} - \bar{r}_{i.}\right|}{\bar{r}_{i.}} \qquad (10)$$

where: r_{ij} represents the rank in year *j* from somaclone *i*; $\bar{r}_i$ represents the average rank across three years for each somaclone, and *N* represents the number of years. In accordance with Thennarasu (1995), stability parameters ($NP^{(i)}$) were computed as:

$$NP^{(1)} = \frac{\sum_{j=1}^{n} |r^*_{ij} - M^*_{di}|}{N} \quad (11)$$

$$NP^{(2)} = \frac{\left[\sum_{j=1}^{n} |r^*_{ij} - M^*_{di}| / M_{di}\right]}{N} \quad (12)$$

$$NP^{(3)} = \frac{\sqrt{\frac{\sum (r^*_{ij} - r^*_{i.})^2}{N}}}{\bar{r}_{i.}} \quad (13)$$

$$NP^{(6)} = \frac{2x\left[\sum_{j=1}^{n-1} \sum_{j'=j+1}^{n} |r^*_{ij} - r^*_{i.}| / \bar{r}_{i.}\right]}{N(N-1)} \quad (14)$$

where: r*ij represents the rank of somaclone ‘*i*’ in year ‘*j*’ (the data must be adjusted first); M^*_{di} – media rank of adjusted data; M_{di} represents the same parameter derived from the raw data; N represents the number of years. The nonparametric stability measure (*K*R) proposed by Kang (1988). This strategy assigned 1 (one) weighting to yield performance and stability variance to select stable and high-yielding potato somaclones. To estimate the combined stability measures (parametric and nonparametric), we used the online software STABILITYSOFT (Pour-aboughadareh *et al.* 2019). Hierarchical Clustering Analysis (HCA) was used to integrate the stability of potato somaclones based on ranks of combined stability assessment.

The GGE biplot model utilizing the formula from Yan and Tinker (2006) was:

$$Y_{ij} - \bar{Y}_j = \lambda_1 \zeta_{i1} \eta_{j1} + \lambda_2 \zeta_{i2} \eta_{j2} + \varepsilon_{ij} \quad (15)$$

where: *Yij* represents the mean performance of somaclone *i* in year *j*; $\bar{Y}j$ represents the mean performance for all somaclone in year *j*; λ_1 is the singular value of PC1; λ_2 is the singular value of PC2; ζ_{i1} is the PC1 score and ζ_{i2} is the PC2 score for somaclone *i*; η_{j1} is the PC1 score and η_{j2} is the PC2 score, for year *j*; ε_{ij} is the model's residual linked to the somaclone *i* in year *j*. In this research, the GGE biplot used is the which won where pattern. To calculate the GGE biplot, use the online software PBStat.

Using the following formula, the sustainability index (SI) was calculated (Tuteja 2006):

$$SI = \left[\frac{(Y - \sigma n)}{YM}\right] x\ 100 \quad (16)$$

where: Y represents the potato somaclones' mean performance, σn denotes the standard deviation, and YM indicates the somaclones' best performance throughout any given year. The SI values were arbitrarily divided into five groups: very high (above 80%), high (61% to 80%), moderate (41% to 60%), low (21% to 40%), and very low (up to 20%). The SI was computed using Ms. Excel 2013.

RESULTS

Somaclone-by-growing season interactions (GEIs) on potato yields

Table 3 displayed the results of the combined ANOVA for potato somaclones assessed throughout three growing seasons. Table 3 shows that the yield varied significantly ($p<0.01$) across somaclones (genotype/G), environment (growing season/E) and GEIs. The highest difference was shown by environmental influence (season) at 41.49%, while the GEIs influence was 37.38%, and somaclones were 21.14%.

There are variations in potato yield performance under various environments, in this case, the growing season or year in Lembang, West Java, Indonesia, as indicated by the significant effect of somaclones, environment, and their interactions. Table 3 presented that the average yield range across the three growing seasons was from 7.66 t/ha (growing season 1) to 55.81 t/ha (growing season 2). The average data for the three growing seasons recorded an average yield of 26.90 t/ha. The resulting coefficient of variation (CV) value is included in the moderate category (14.64%). These results confirm that it is necessary to out further testing using stability analysis to obtain high-yielding and stable potato somaclones at three growing seasons.

Visually, heatmap GEIs divided the environment (growing seasons) into two clusters (Figure 1). The first environmental group consisted of Y2 (growing season 2021), whereas the members of the second environmental group were Y1 (growing season 2020) and Y3 (growing season 2022). The potato somaclones tested had a range of scattered colours, according to the GEIs response pattern shown in Figure 1. The GEIs' magnitude is shown by the colours in this pattern. A dense colour indicates a

Table 3

Combined ANOVA of potato yield during three years di Lembang, West Java, Indonesia

Source	Df	SS	MS	F		SS [%]
Total	341	26.09	–	*	–	–
Genotypes (G)	37	3.50	0.09	2.36	**	21.14
Season (E)	2	6.87	3.44	31.54	**	41.49
Replication	6	0.65	0.11	2.72	*	–
Interactions (GEIs)	74	6.19	0.08	2.09	**	37.38
Error	222	8.89	0.04	*	–	–
CV [%]	14.64	–	–	–	–	–
Mean [t/ha]	26.90	–	–	–	–	–

Df – degree freedom; SS – sum of square; MS – mean of square; $^{*}P<0.05$; $^{**}P<0.01$

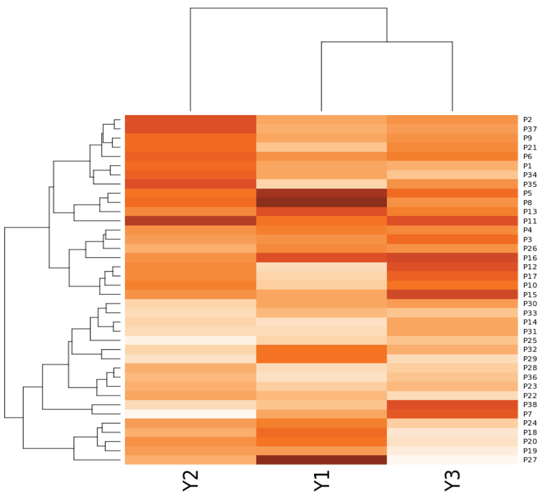

Figure 1. GEIs heatmap between potato somaclones and the environment during three growing seasons. Somaclones code see Table 1. Y1 – first years (2020); Y2 – second years (2021); Y3 – third years (2022).

strong and positive interaction between the potato somaclone being tested and its environment, and vice versa (Pham *et al*. 2022). P5, P8 and P27 show the most intense colours against Y1. This means all three have the highest values in the second growing season (2021) compared to the other somaclones. Likewise, P11 has a positive interaction with Y2. The variations in the interaction patterns between the potato somaclones tested showed differences in the response of each tested potato to changes in the growing season. Differences in the growing season can also be seen in Table 2, where each test year has a different average rainfall, temperature and humidity.

Stability analysis of potato yield using combined stability (parametric and non-parametric)

The average yield and parameters of the combined stability analysis of potato somaclones are shown in Table 4. The average yield ranged from 11.34 to 29.45 t/ha, where 20 somaclones were identified as having yields greater than the average (>20.18 t/ha), while the other 18 somaclones had below-average yields. According to the model (Eberhart & Russell 1966), estimations of the regression coefficient (bi) = 1 and low S^2di (close to zero) were used to determine genotype stability. The bi-measurement identified P3, P20 and P26 as somaclones that have low GEIs (stable), while S2di identified P4, P23 and P6 as stable somaclones. Based on the coefficient of variation (CVi) parametric stability model, P32, P16 and P13 were classified as the most stable somaclones. The mean-variance component (θi) assigned P7, P27, and P38 as the most stable somaclones. The most stable somaclones according to three different parametric stability measures (GE Plaisted variance component (θ(i), Shukla stability variance ($\sigma^2 i$), and Wricke equivalent (Wi^2)) were P4, P23 and P26.

Stability estimation for each somaclone using a non-parametric stability model showed that the $S^{(1)}$ and $S^{(2)}$ measurements identified the P23, P5 and P4 somaclones as the most stable (Table 5). $S^{(3)}$ iden-

T a b l e 4

Stability analysis of potato somaclones based on parametric and non-parametric measurements

Gen	Y	$S^{(1)}$	$S^{(2)}$	$S^{(3)}$	$S^{(6)}$	$NP^{(1)}$	$NP^{(2)}$	$NP^{(3)}$	$NP^{(4)}$	KR	W_i^2	σ^2_i	s^2d_i	b_i	CVi	$\theta_{(i)}$	θ_i
P1	21.80	15.17	143.58	26.51	2.03	5.75	0.49	0.51	0.93	28	109.33	36.80	11.10	1.21	87.60	60.71	49.59
P2	24.54	12.50	108.25	14.27	1.25	8.75	0.63	0.55	0.55	37	219.53	75.57	15.69	1.40	89.86	59.67	68.45
P3	22.41	7.33	33.33	4.17	0.67	6.75	0.31	0.33	0.31	16	43.61	13.68	5.97	1.05	73.07	61.34	38.34
P4	22.85	5.67	20.67	2.30	0.44	4.00	0.21	0.19	0.21	12	9.73	1.76	0.47	1.10	72.89	61.66	32.54
P5	28.20	4.67	13.33	1.25	0.38	9.50	0.42	0.35	0.15	21	132.67	45.01	13.90	1.23	68.96	60.49	53.59
P6	24.86	6.33	24.67	2.47	0.53	7.50	0.36	0.29	0.21	16	86.53	28.78	2.67	1.31	80.74	60.93	45.69
P7	16.08	19.33	251.33	32.78	2.00	10.25	0.42	0.61	0.84	69	699.85	244.57	78.24	0.53	97.78	55.10	150.67
P8	27.55	8.83	52.25	5.02	0.74	12.25	0.45	0.41	0.28	28	189.08	64.86	23.06	1.20	71.20	59.95	63.24
P9	23.02	12.17	88.92	9.79	1.06	7.00	0.46	0.31	0.45	21	97.91	32.78	6.71	1.27	85.50	60.82	47.64
P10	21.69	16.50	177.58	31.81	2.69	9.50	0.63	0.63	0.99	31	111.55	37.58	11.44	1.21	88.11	60.69	49.97
P11	29.45	18.17	250.92	28.68	1.77	11.50	0.47	0.48	0.69	32	224.82	77.43	2.92	1.54	80.00	59.61	69.36
P12	21.84	19.50	254.25	44.22	3.07	10.75	0.91	0.72	1.13	47	232.90	80.28	27.98	1.23	93.14	59.54	70.74
P13	25.16	15.50	161.58	21.31	1.56	6.75	0.48	0.42	0.68	14	74.38	24.50	9.68	1.10	68.79	61.05	43.61
P14	14.15	8.50	44.92	16.33	2.30	11.50	1.77	1.42	1.03	54	128.84	43.66	11.76	0.74	87.53	60.53	52.93
P15	23.39	16.33	169.67	24.83	1.76	8.75	0.57	0.53	0.80	26	123.30	41.71	14.54	1.18	80.22	60.58	51.98
P16	26.64	16.83	179.58	21.77	1.74	12.00	0.41	0.50	0.68	20	120.40	40.69	15.38	1.14	68.45	60.61	51.49
P17	21.50	15.33	153.67	24.92	2.27	9.50	0.60	0.62	0.83	42	170.72	58.40	19.70	1.22	91.50	60.13	60.10
P18	17.98	15.50	165.58	33.68	2.47	10.50	0.98	0.80	1.05	52	210.96	72.56	24.70	0.77	77.09	59.75	66.99
P19	16.86	11.83	86.25	18.82	2.11	6.75	0.92	0.81	0.86	49	161.37	55.11	21.61	0.88	89.55	60.22	58.50
P20	19.36	14.17	121.58	21.14	2.03	8.25	0.53	0.62	0.82	46	173.35	59.32	24.47	0.95	83.70	60.10	60.55
P21	22.32	11.83	88.92	12.86	1.49	8.75	0.40	0.49	0.57	35	140.88	47.90	11.99	1.29	90.58	60.41	54.99
P22	16.32	5.67	25.67	6.16	1.20	6.25	0.66	0.67	0.45	37	58.17	18.80	6.90	0.88	85.43	61.20	40.83
P23	16.62	3.33	7.00	1.56	0.59	2.75	0.32	0.33	0.25	30	21.12	5.76	1.96	0.90	82.78	61.55	34.49
P24	19.45	10.67	73.67	12.63	1.26	6.50	0.37	0.49	0.61	29	66.06	21.57	8.66	0.91	74.68	61.12	42.18
P25	11.34	8.33	43.67	13.79	1.89	10.00	1.67	1.33	0.88	71	250.60	86.51	9.77	0.49	77.39	59.37	73.77
P26	20.70	6.67	27.00	3.95	0.78	5.00	0.19	0.29	0.33	23	27.66	8.06	3.53	0.93	69.84	61.49	35.61
P27	19.03	20.00	247.00	42.34	2.63	12.00	0.74	0.78	1.14	60	651.11	227.43	82.56	0.67	90.57	55.56	142.33
P28	14.81	9.67	58.00	15.82	2.00	7.75	0.80	0.81	0.88	38	54.84	17.63	5.95	0.86	91.70	61.23	40.26
P29	15.12	17.17	186.92	35.60	2.86	14.00	0.80	0.90	1.09	66	325.25	112.77	22.68	0.51	70.12	58.66	86.55
P30	16.52	8.00	44.00	7.76	1.06	6.50	0.53	0.55	0.47	42	111.40	37.53	8.17	0.72	71.11	60.69	49.94
P31	13.69	11.83	93.58	22.02	2.43	9.75	1.12	0.85	0.93	57	138.28	46.98	9.54	0.68	82.63	60.44	54.55
P32	17.72	14.00	120.33	18.51	1.85	8.75	0.45	0.54	0.72	52	199.37	68.48	17.18	0.66	66.91	59.86	65.00
P33	14.24	10.67	79.00	16.34	1.72	7.25	0.86	0.69	0.74	50	113.92	38.41	3.33	0.64	70.61	60.67	50.38
P34	21.51	14.00	119.00	15.87	1.51	7.75	0.39	0.47	0.62	44	194.00	66.59	22.45	1.23	93.07	59.91	64.08
P35	22.36	16.50	167.58	22.10	1.71	9.50	0.53	0.59	0.73	48	348.39	120.91	33.44	1.41	103.28	58.44	90.51
P36	14.45	14.17	140.92	31.91	2.53	7.50	1.00	0.70	1.07	40	57.65	18.61	5.19	0.82	89.78	61.20	40.74
P37	23.49	12.00	90.67	10.88	1.28	8.25	0.62	0.48	0.48	37	215.65	74.21	17.82	1.36	92.15	59.70	67.79
P38	17.72	19.00	235.00	34.39	2.54	11.50	0.60	0.63	0.93	36	374.11	129.96	48.85	0.78	90.16	58.20	94.91

For somaclones code see Table 1. Y − yield [t/ha]; $S^{(1)}$, $S^{(2)}$, $S^{(3)}$, $S^{(6)}$ − Nassar and Huhn (1987) and Huehn (1990); $NP^{(1)}$, $NP^{(2)}$, $NP^{(3)}$, $NP^{(4)}$ − Thennarasu (1995); KR − Kang (1988); W_i^2 − Wricke (1962); σ^2_i − Shukla (1972); s^2d_i and bi − Eberhart and Russell (1966); CVi − Francis and Kannenberg (1978); $\theta_{(i)}$ − Plaisted (1960); θ_i − Plaisted and Peterson (1959)

T a b l e 5

Stability rank's of potato somaclones based on parametric and non-parametric measurements

Gen	Y	$S^{(1)}$	$S^{(2)}$	$S^{(3)}$	$S^{(6)}$	$NP^{(1)}$	$NP^{(2)}$	$NP^{(3)}$	$NP^{(4)}$	KR	W_i^2	σ^2_i	s^2d_i	bi	CVi	$\theta_{(i)}$	θ_i	SR	SD	AR
P1	16	25	25	29	27	4	17	16	31	10	12	12	17	16	24	12	27	320	7.50	18.82
P2	7	20	20	15	11	19	26	19	12	18	30	30	24	33	28	30	9	351	7.84	20.65
P3	12	7	7	6	5	8	3	5	6	3	4	4	9	1	11	4	35	130	7.39	7.65
P4	11	3	3	3	2	2	2	1	2	1	1	1	1	5	10	1	38	87	8.72	5.12
P5	2	2	2	1	1	23	11	7	1	6	19	19	21	19	4	19	20	177	8.43	10.41
P6	6	5	4	4	3	13	5	3	3	3	10	10	3	27	17	10	29	155	7.96	9.12
P7	31	36	37	33	24	29	10	22	25	37	38	38	37	35	37	38	1	508	10.36	29.88
P8	3	11	11	7	6	37	12	8	5	10	25	25	31	14	9	25	14	253	9.65	14.88
P9	10	19	16	10	9	11	14	4	8	6	11	11	10	24	22	11	28	224	6.35	13.18
P10	17	30	31	31	36	23	25	25	32	14	14	14	18	15	25	14	25	389	7.24	22.88
P11	1	34	36	30	21	32	15	11	18	15	31	31	4	38	15	31	8	371	11.50	21.82
P12	15	37	38	38	38	31	32	30	37	27	32	32	34	21	36	32	7	517	8.40	30.41
P13	5	27	27	23	16	8	16	9	17	2	9	9	15	6	3	9	30	231	8.53	13.59
P14	36	10	10	18	30	32	38	38	33	33	18	18	19	23	23	18	21	418	8.96	24.59
P15	9	29	30	27	20	19	21	17	22	9	17	17	22	13	16	17	22	327	5.83	19.24
P16	4	32	32	24	19	35	9	15	16	5	16	16	23	10	2	16	23	297	9.56	17.47
P17	19	26	26	28	29	23	22	23	24	23	23	23	27	18	32	23	16	405	3.88	23.82
P18	24	27	28	34	32	30	34	32	34	31	28	28	33	22	13	28	11	469	6.61	27.59
P19	27	15	15	21	28	8	33	33	26	29	22	22	28	9	26	22	17	381	7.30	22.41
P20	22	23	23	22	26	17	18	24	23	26	24	24	32	2	20	24	15	365	6.14	21.47
P21	14	15	16	13	14	19	8	14	13	16	21	21	20	26	31	21	18	300	5.30	17.65
P22	30	3	5	8	10	5	27	27	9	18	7	7	11	8	21	7	32	235	9.50	13.82
P23	28	1	1	2	4	1	4	6	4	13	2	2	2	7	19	2	37	135	10.19	7.94
P24	21	13	13	12	12	6	6	13	14	12	8	8	13	4	12	8	31	206	6.11	12.12
P25	38	9	8	14	23	28	37	37	27	38	33	33	16	37	14	33	6	431	11.39	25.35
P26	20	6	6	5	7	3	1	2	7	8	3	3	6	3	5	3	36	124	8.27	7.29
P27	23	38	35	37	35	35	28	31	38	35	37	37	38	29	30	37	2	545	8.59	32.06
P28	33	12	12	16	24	15	29	34	28	21	5	5	8	11	33	5	34	325	10.70	19.12
P29	32	33	33	36	37	38	30	36	36	36	34	34	30	36	6	34	5	526	9.55	30.94
P30	29	8	9	9	8	6	18	20	10	23	13	13	12	25	8	13	26	250	7.11	14.71
P31	37	15	19	25	31	27	36	35	30	34	20	20	14	28	18	20	19	428	7.42	25.18
P32	25	21	22	20	22	19	13	18	19	31	27	27	25	30	1	27	12	359	7.22	21.12
P33	35	13	14	19	18	12	31	28	21	30	15	15	5	31	7	15	24	333	8.64	19.59
P34	18	21	21	17	15	15	7	10	15	25	26	26	29	20	35	26	13	339	7.06	19.94
P35	13	30	29	26	17	23	20	21	20	28	35	35	35	34	38	35	4	443	9.08	26.06
P36	34	23	24	32	33	13	35	29	35	22	6	6	7	12	27	6	33	377	11.05	22.18
P37	8	18	18	11	13	17	24	12	11	18	29	29	26	32	34	29	10	339	8.31	19.94
P38	25	35	34	35	34	32	23	26	29	17	36	36	36	17	29	36	3	483	8.90	28.41

For somaclones code see Table 1. Y – yield [t/ha], $S^{(1)}$, $S^{(2)}$, $S^{(3)}$, $S^{(6)}$ – Nassar and Huhn (1987) and Huehn (1990); $NP^{(1)}$, $NP^{(2)}$, $NP^{(3)}$, $NP^{(4)}$ – Thennarasu (1995); KR – Kang (1988); W_i^2 – Wricke (1962); σ^2_i – Shukla (1972); s^2d_i and bi – Eberhart and Russell (1966); CVi – Francis and Kannenberg (1978); $\theta_{(i)}$ – Plaisted (1960); θ_i – Plaisted and Peterson (1959); SR – Sum of rank; SD – standard of deviation; AR – average of rank tified somaclones P5, P23 and P4 as the most stable, and S(6) identified somaclones P5, P4 and P6 as the most stable somaclones. NP(1) identified P23, P4 and P26 as the most stable somaclones, NP(2) identified P26, P4 and P3 as the most stable somaclones, NP(3) identified P4, P26 and P6 as the most stable somaclones, NP(4) identified P5, P4 and P6 as the most stable somaclones, while KR identified the P4, P13 and P3 as the most stable somaclones. Table 5 displays each measurement's stability rank. Table 5 indicates that the P4 somaclone was the most stable since it had the lowest mean rank (AR), whereas P27 had the greatest AR and was the least stable or adaptive somaclone in a given region/ season.

Cluster analysis/ HCA (dendrogram) was also conducted to classify potato somaclones. In this investigation, the dendrogram separated the potato somaclones into two primary clusters (Figure 2). The first cluster (KI) is an unstable somaclone cluster. Three sub-clusters were created from this cluster, namely the first unstable medium yield sub-clusters consisting of somaclones P2, P37, P21, P34, P32, P1, P15, and P10. The second, unstable low yield sub-clusters consisted of somaclones P17, P19, P20, P28, P36, P14, P31, P33, P25, P7, P35, P12, P27, P38, P18, and P29. The third, unstable high-yield sub-clusters consisted of somaclones P13, P16, and P11, which have a high average yield and a high average stability rank. The second group (K2) is a stable somaclone cluster. There were two sub-clusters inside this cluster: the stable high-yield sub-cluster included genotypes P5, P8, P6, P9, P3, P26, and P4. They were greater than the overall average yield and had a low average stability rank. The second, stable

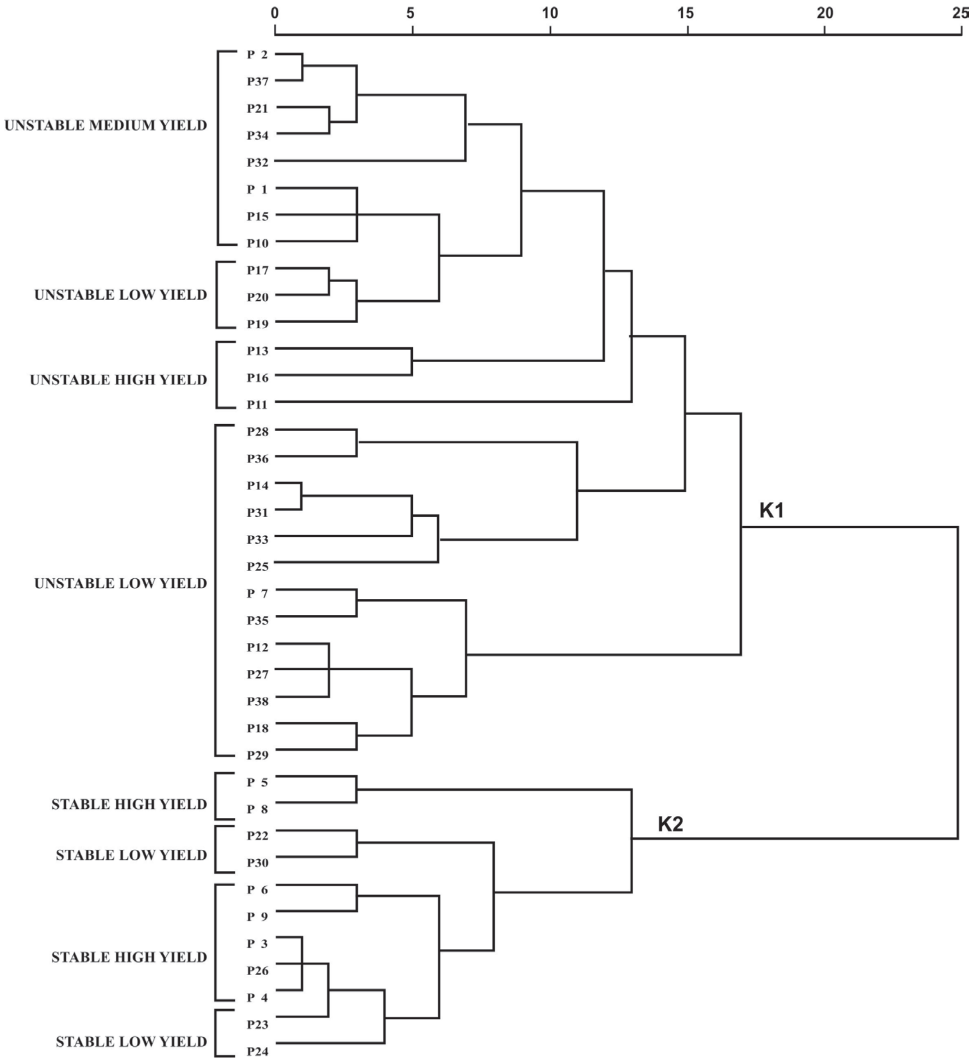

Figure 2. Potato somaclones grouping based on stability rank. For somaclones code see Table 1.

low-yield sub-clusters consisted of genotypes P22, P30, P23, and P24. They had low yields and were unstable in all test seasons.

Stability analysis based on GGE biplot

A visualization of yield stability for 37 potato somaclones with one control genotype is presented in Figure 3. PC1 and PC2 accounted for 54.3 and 26.3%, respectively, of the overall yield variation. The GGE biplot ('which won where' pattern) shows that the three growing seasons had eight sectors with different peak somaclones. Each environment (growing season) was in a different sector, where the first planting season was in sector 1, containing P27 as the peak somaclone. Sector two has a peak somaclone of P29, sector 3 has a peak somaclone of P25, sector 4 has a peak somaclone of P27, sector 5 has no peak somaclone, sector 6 contains planting season 3 with a peak somaclone of P12, sector 7 contains planting season 2 and peak somaclone P11, while sector 8 contains the peak somaclone of P6. Top-performing somaclones in each sector suggest high yields in that sector's environment. The yields of somaclones that are near the central axis (0.00) are relatively stable. In this test, the stable somaclones were P3, P4, P22, P23, and P26.

Estimating the stability of potato yields using the sustainability index (SI)

Table 6 presents the findings from the sustainability index (SI) analysis. Potato yields are predicted to have SI values between low (23.25%) to very high (91.63%). Moderate SI values were indicated by somaclones P6, P11, P14, P15, P18, P20, P23, P24, P25, and P31. High SI values were indicated by somaclones P3, P4, P5, P8, P13, P16, P26, P29, P30, and P33. While the very high SI value is shown by P32 (91.63%).

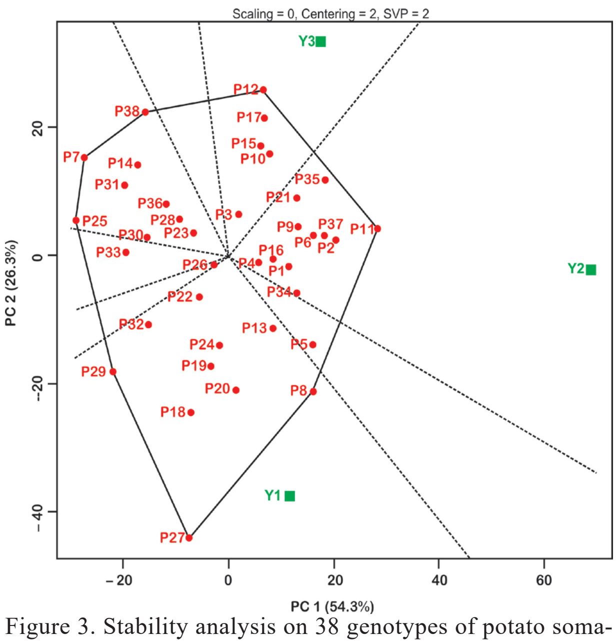

Figure 3. Stability analysis on 38 genotypes of potato somaclones based on GGE biplot; Y1 − first years (2020); Y2 − second years (2021); Y3 − third years (2022).

Significant variations in various growing seasons were found by the estimated analysis of variance in SI for potato yields, demonstrating genetic variability within the analysed someclones. The somaclone with the best performance was P32, which had an average yield of 23.62 t/ha and an SI value of 91.63% (very high) (Table 6). According to Verma *et al.* (2013), the best performance with a high SI value can be interpreted as a measure of how closely the best and average performances are related. The next best somaclone with high yield and high SI value was P3 (29.88 t/ha with SI = 66.72%), P4 (30.47 t/ha with SI = 61.28%), P5 (37.60 t/ha with SI = 73.14 %), P8 (36.73 t/ha with SI = 65.36%), P13 (33.55 t/ha with SI = 74.00%), P16 (35.52 t/ha with SI = 80.01 %), and P26 (29.08 t/ha with SI = 72.81). Several other somaclones had high SI values but low yields (below average) namely P29 (20.15 t/ha with SI = 68.09%), P30 (22.03 t/ha with SI = 67.39%), and P33 (18.99 t/ha with SI = 72.19%). These somaclones were identified as stable but low yields. Other somaclones with high yields above average but with low and moderate SI, suggested that the somaclone's performance varied depending on the growing season or that it would give better in a favorable growing season. Meanwhile, somaclones with low yields and low SI showed poor adaptability and yield performance.

DISCUSSION

The results of the combined ANOVA on the potato somaclones tested showed that the effect of growing season is the most contributed to the diversity of potato yields (41.49%), followed by GEIs effects (E) (37.38%), and somaclone effects (21.14%) (Table 3). Researchers have also reported that GEIs affect potato yields (Worku *et al*. 2018). The interaction patterns and groupings between the potato somaclones tested and their growing season (environment) are also displayed in the heatmap GEIs (Figure 1). There are two primary clusters of the environment. The potato somaclones tested had a diverse and distributed coloration, as seen by the GEIs response pattern displayed in Figure 1. This suggests

Table 6

Sustainability Index (SI) of potato yield during three growing seasons

Code	M1	M2	M3	mean	stdev	YM	SI	Criteria
P1	16.83	46.04	24.32	29.06	12.38	46.04	36.23	Low
P2	17.08	52.56	28.52	32.72	14.79	52.56	34.11	Low
P3	20.40	34.73	34.50	29.88	6.70	34.73	66.72	High
P4	22.22	38.72	30.46	30.47	6.74	38.72	61.28	High
P5	34.51	44.61	33.68	37.60	4.97	44.61	73.14	High
P6	19.89	47.55	31.98	33.14	11.32	47.55	45.89	Moderate
P7	17.43	9.79	37.09	21.44	11.50	37.09	26.78	Low
P8	35.68	45.65	28.87	36.73	6.89	45.65	65.36	High
P9	16.45	46.51	29.12	30.69	12.32	46.51	39.50	Low
P10	11.89	41.52	33.33	28.92	12.49	41.52	39.55	Low
P11	23.99	55.81	37.98	39.26	13.02	55.81	47.01	Moderate
P12	9.04	39.71	38.62	29.12	14.21	39.71	37.57	Low
P13	30.27	39.57	30.81	33.55	4.27	39.57	74.00	High
P14	7.66	22.90	26.03	18.86	8.02	26.03	41.64	Moderate
P15	16.45	37.81	39.30	31.19	10.44	39.30	52.80	Moderate
P16	29.75	37.57	39.23	35.52	4.13	39.23	80.01	High
P17	9.80	40.43	35.76	28.66	13.47	40.43	37.57	Low
P18	26.19	31.17	14.56	23.98	6.96	31.17	54.58	Moderate
P19	18.62	36.29	12.52	22.48	10.08	36.29	34.16	Low
P20	23.60	38.77	15.08	25.82	9.80	38.77	41.31	Moderate
P21	13.23	46.75	29.31	29.76	13.69	46.75	34.38	Low
P22	14.43	34.00	16.83	21.75	8.72	34.00	38.33	Low
P23	12.03	32.00	22.45	22.16	8.15	32.00	43.78	Moderate
P24	22.86	35.04	19.91	25.94	6.55	35.04	55.33	Moderate
P25	10.36	13.92	21.08	15.12	4.46	21.08	50.56	Moderate
P26	21.73	31.97	29.08	27.59	4.31	31.97	72.81	High
P27	36.32	30.59	9.21	25.37	11.67	36.32	37.74	Low
P28	8.23	31.07	19.95	19.75	9.33	31.07	33.54	Low
P29	24.78	18.19	17.49	20.15	3.28	24.78	68.09	High
P30	16.69	22.77	26.62	22.03	4.09	26.62	67.39	High
P31	9.10	20.77	24.87	18.25	6.68	24.87	46.51	Moderate
P32	24.67	22.24	23.96	23.62	1.02	24.67	91.63	Very High
P33	14.32	20.93	21.71	18.99	3.32	21.71	72.19	High
P34	16.83	48.29	20.91	28.68	13.97	48.29	30.45	Low
P35	9.33	52.37	27.72	29.81	17.63	52.37	23.25	Low
P36	7.77	28.77	21.24	19.26	8.69	28.77	36.73	Low
P37	15.43	51.33	27.19	31.32	14.94	51.33	31.90	Low
P38	12.53	20.16	38.18	23.62	10.75	38.18	33.70	Low

For somaclones code see Table 1. M1 − first years (2020); M2 − second years (2021); M3 − third years (2022); stdev − standard deviation; YM − yield maximum; MR − moderate resistance.

an interaction with the growing season (environment). The intensity of the simulated GEIs is shown by the ensuing colour difference, and the dense colour denotes strong positive interactions (Pham *et al*. 2022; Susanto *et al.* 2023). In this study, P5, P8 and P27 showed the most intense colour against Y2. This means that all three have the strongest interaction response and have the highest value in the second year of the planting season (2021) compared to the others. It shows that variations in potato yields are strongly influenced by the environment; in this study, changes in growing seasons.

Significant variation indicates that one or more potato somaclones that have different responses to changes in the growing season, probably due to the genetic background of the potato somaclones used. The population used a result of gamma-ray mutations previously propagated through a tissue culture process (Krishna *et al*. 2016). Variations that occur during tissue culture are somaclonal variations that are epigenetic (not genetic), causing the traits being tested to be unstable, usually caused by environmental conditions (Ferreira *et al*. 2023). Although it was conducted up to 6× subcultures, selection activities in the field proved that some somaclones were phenotypically unstable. Nonetheless, this variation can be employed in potato genetic improvement projects to create genetic diversity and support the release of new superior varieties that are resistant to abiotic stresses brought on by seasonal and climatic variations as well as diseases and pests (Hoque & Morshad 2014; Krishna *et al*. 2016). It shows that the response of potato somaclones to environmental changes is very high so further testing is needed to obtain potato somaclones that can adapt to environmental changes.

The emergence of the effect of GEIs, which makes a large contribution, shows that potato yields vary in each experimental season. This makes the potato breeding program less efficient (Maulana *et al*. 2022; Wicaksana *et al.* 2022). There are strong interactions (GEIs), possibly caused by significant differences in environmental conditions (Table 2). Several researchers also revealed that environmental differences and growing seasons could cause significant variations in crop yields (Maulana *et al*. 2022; Wicaksana *et al*. 2022; Utami *et al*. 2023). Thus, the selection of superior genotypes must be carried out using various advanced statistical analyses. GEIs have also been shown in other research to significantly impact crop yields, including sweet potato yields (Ngailo *et al*. 2019; Maulana *et al*. 2022), soybeans (Susanto *et al.* 2022), and maize (Wicaksana *et al*. 2022). The presence of significant GEIs necessitates further analysis with various approaches to estimate the stability of the results (Vaezi *et al.* 2019; Maulana *et al*. 2023). Therefore, various stability measures were used to classify potato somaclones into a more defined group.

Several techniques have been used in conjunction with the average results of somaclone stability ranks as a selection index (Vaezi *et al*. 2019; Maulana *et al*. 2022). To identify the superior potato somaclones, this study employed the GGE biplot, sustainability index (SI), and combined stability analysis (parametric and nonparametric). Table 4 displays the findings of the potato somaclones' parametric and non-parametric stability analyses, while Table 5 displays the stability ranks. Based on Table 4 and Table 5, it can be seen that each stability has differences in estimating stable somaclones. However, there are three stability models that exhibit the same pattern in assessing genotype stability. Namely the Wricke equivalence stability model (Wi^2), the Shukla stability variance ($\sigma^2 i$), and the Plaisted GE variance component ($\theta_{(i)}$), with P4 as the most stable somaclone. It shows that the three measurements (Wi^2, $\sigma^2 i$, $\theta_{(i)}$) have the equivalent abilities in assessing the stability performance of potato yields, so one of the three models can be used to select stable somaclones (Vaezi *et al.* 2019; Maulana *et al.* 2022). Based on the average rank (AR), the P4 somaclone also has a small value, so it was declared the most stable somaclone. The same thing was also conveyed by (Vaezi *et al*. 2019), who stated that the genotype with the lowest average rank had the highest stable yield in multi-location testing.

Potato somaclones were categorized into distinct groups using cluster analysis (dendrogram). Figure 2 shows the outcomes of the dendrogram analysis. The dendrogram analysis divides the potato somaclones into two primary clusters. The first cluster (KI) is an unstable somaclone cluster. Three sub-clusters were created from this cluster, namely unstable medium yield sub-cluster consisting of somaclones P2, P37, P21, P34, P32, P1, P15, and P10.

The second, unstable low yield sub-clusters consists of somaclones P17, P19, P20, P28, P36, P14, P31, P33, P25, P7, P35, P12, P27, P38, P18, and P29. The third, unstable high-yield sub-clusters consist of soma-clones P13, P16 and P11 with high average values for yield and stability rank's. As opposed to stable somaclones, specific adapted somaclones have more advantages in responding to environmental changes (Ngailo *et al.* 2019). Therefore, soma-clones in the third sub-cluster are highly recommended as candidates for environmentally specific superior varieties.

The second group (K2) is a stable somaclone cluster. This cluster is divided into two sub-clusters, namely the first stable high-yield sub-cluster consisting of somaclones P5, P8, P6, P9, P3, P26, and P4. They have yields greater than the overall average and have a low average stability rank. This group is ideal, because it has high yields (above the overall average) and is stable in the three test growing seasons (Vaezi *et al*. 2019; Maulana *et al*. 2022). The second group is stable low-yield sub-clusters consisting of somaclones P22, P30, P23, and P24. They had low yields and were unstable in all test seasons. By using combined stability analysis, a number of researchers have also been successful in choosing stable and high-yielding genotypes, including soybeans (Susanto *et al*. 2023), maize (Wicaksana *et al*. 2022), sweet potato (Maulana *et al*. 2022), and barley (Vaezi *et al.* 2019). Thus, the somaclones in the high-yielding and stable sub-cluster can be proposed as a candidate for superior potato somaclones.

Visualization of potato yield stability using GGE biplot (Figure 3). Based on Figure 3, the GGE biplot graph accounts for 80.60% (PC1 and PC2) of the total variation for 38 potato somaclones. The 'which won where' pattern shows that the three growing seasons have seven sectors with different top potato soma-clones. Three sectors have environmental points (planting seasons), namely sector 1 with P27 as the top somaclone, sector 6 with P12 as the top somaclone, and sector 7 with P11 as the top somaclone. Somaclones that are at the top of each sector indicate that these somaclones have high yields in environments located in that sector (Maulana *et al*. 2023). The peak somaclones in the sector containing the environment showed that these somaclones had the best yields in the growing environment (Mustamu *et al.* 2018). Therefore, these somaclones are suitable to be used as environment-specific.

The GGE biplot analysis results indicated that a number of identified somaclones were located in close proximity to the axis centre. The somaclones were P3, P4, P22, P23, and P26. Numerous studies found that stable genotypes were those that were near the central axis (0.00) (Mustamu *et al.* 2018; Wicaksana *et al.* 2022). The results of GGE biplot, parametric and non-parametric, and biplot measurements illustrated a comparable ability to choose the ideal somaclones (high yielding and stable). Table 6 displays the findings of the sustainability index (SI) investigation. According to several studies, a high SI value denotes a genotype's stability rate (Bose *et al.* 2014; Filio *et al.* 2023; Utami *et al.* 2023). According to Tuteja *et al.* (2006), there are five categories of SI values: very high, high, medium, low, and very low. This hierarchy serves as the foundation for the distribution of SI values. In this research, potato yields showed SI values between 23.25% (Low) to 91.63% (Very High). High SI values were indicated by somaclones P3, P4, P5, P8, P13, P16, P26, P29, P30, and P33. While the very high SI value is shown by P32 (91.63%). This somaclone showed the best performance with an average yield of 23.62 t/ha (Table 6). A high SI value for the best performance might be interpreted as a measure of how closely the average and best performances are related (Verma *et al.* 2013; Filio *et al.* 2023). The next ideal somaclones were P3, P4, P5, P8, P13, P16, and P26, all with high SI values and high yielding. Other somaclones with low average yields and SI values are the least ideal genotypes (Filio *et al.* 2023; Maulana *et al.* 2023). So, in this measurement, these genotypes were not selected as superior genotypes. Potato somaclones with low SI values but high yields may also be caused by epigenetic effects, where changes in gene expression are influenced by the environment, which causes DNA methylation so that the phenotype 'as if' changes and will come back when the environment supports it.

Generally, the GGE biplot selected five stable somaclones, namely P3, P4, P22, P23, and P26. Combining parametric and non-parametric measurements selected seven somaclones P3, P4, P5, P6, P8, P9, and P26, while SI selected eight superior somaclones, namely: P3, P4, P5, P8, P13, P16, P26, and P32. Based on a combination of stability model approaches, three new ideal somaclones were selected in the three testing seasons, namely genotypes P3, P4 and P26. Thus, the three selected potato somaclones can be suggested as the new potential cultivars with high yields and consistency in three testing seasons and as material for future research on potatoes.

CONCLUSIONS

Potato yields are strongly influenced by the effects of genotype (somaclones), growing season, and GEIs. GEIs gave the highest contribution to potato yield variation, which was 37.36%. Combining parametric and non-parametric measurements selected seven somaclones P3, P4, P5, P6, P8, P9, and P26. GGE biplot selected five stable somaclones, namely P3, P4, P22, P23, and P26, while SI selected eight high-yielding and stable somaclones, namely: P3, P4, P5, P8, P13, P16, P26, and P32. Based on a combination of various stability measurements, three potato somaclones were selected that had high yields and were stable for three growing seasons, namely somaclones P3, P4 and P26. These three somaclones can be recommended as new superior somaclones and as material for the next potato plant breeding program.

Author contribution
Conceptualization: H.M., I.R., N.A.W., Methodology: H.M., I.R., N.A.W., Software: H.M. Validation: I.R., N.A.W., K., D.W.U., T.H., A.M., S. Formal analysis: H.M., K. Investigation: H.M., U.J., K., T.H., A.K.K. Resources: I.R. Data curation: N.A.W., H.M., T.H., K., A.K.K., U.J. Writing-original draft: H.M., I.R. Writing-review & editing: N.A.W., K., U.J., D.W.U., A.A., T.H., A.K.K., A.M., S. Visualization: H.M. Supervision: I.R. Project administration: I.R. Funding acquisition: I.R. All co-authors reviewed the final version and approved the manuscript before submission.

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