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# Selection of cassava clones for high fresh root yield and root starch content with stability of performance under Malaysian conditions†

(Pemilihan klon ubi kayu untuk hasil ubi basah dan kandungan kanji dalam ubi yang tinggi serta kestabilan prestasi dalam keadaan Malaysia)

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Key words: cassava, stability, adaptability, selection, fresh root yield, root starch content

**Abstrak**

Lima belas genotip ubi kayu diuji selama dua musim di enam lokasi (di tanah mineral dan tanah gambut dengan saliran serta tiga zon agro-ekologi [AEZ]), dan data hasil ubi basah dan kandungan kanji ubi telah diperoleh. Hasil dan kandungan kanji yang paling tinggi terdapat di Serdang (tanah mineral, AEZ 3 yang tidak mempunyai musim kemarau). Namun begitu, hasil ubi dan kandungan kanji ubi kayu yang ditanam di tanah gambut didapati setanding dengan yang diperoleh di tanah mineral. CM 982-7 mengeluarkan purata genotip yang paling tinggi bagi hasil ubi. Oleh sebab genotip ini mempunyai kandungan sianida yang sederhana rendah, ubi klon CM 982-7 sesuai dimakan. Walau bagaimanapun, oleh sebab kandungan kanjinya yang rendah, genotip ini tidak setanding dengan 17/A dan Black Twig untuk ditanam di tanah mineral, ataupun CM 982-2 di tanah gambut.

Analisis kestabilan dengan menggunakan statistik varians Shukla $\sigma_i^2$, indeks pangkat-jumlah dan statistik tak parametrik Hühn $s_i^3$ dan $s_i^6$ menunjukkan bahawa ketiga-tiga kaedah ini memilih Black Twig sebagai genotip yang stabil untuk hasil ubi dan kandungan kanji yang sederhana tinggi. Walaupun parameter $s_i^3$ dan $s_i^6$ dapat memilih genotip yang stabil untuk hasil ubi dan kandungan kanji, kedua-duanya tidak dapat menjamin genotip yang terpilih mempunyai nilai yang tinggi bagi ciri-ciri tersebut sebagaimana yang dikehendaki.

**Abstract**

Fifteen genotypes of cassava were tested for two seasons in each of six locations (representing mineral soils and drained peat as well as three agro-ecological zones [AEZ]), and data collected on fresh root yield and root starch content. Highest fresh yield and starch content was recorded at Serdang (mineral soil, AEZ 3 with no distinct dry season). However, peat locations were capable of productivity and starch content equivalent to the mineral soil locations. CM 982-7 produced the highest genotype mean for yield over all locations. With its moderately low root cyanide content, this genotype is suitable for eating. However, because of its low starch content, this genotype is not as good as 17/A and Black Twig for planting on mineral soils, nor CM 982-2 for peat.

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Stability analyses using Shukla's variance statistic $\sigma_i^2$, rank-sum indices and Hüh's non-parametric statistics $s_i^3$ and $s_i^6$ showed all three methods were in agreement in selecting Black Twig for being stable for moderately high root yield and starch content. The parameters $s_i^3$ and $s_i^6$ in selecting genotypes stable for fresh yield and starch content were not so successful in ensuring these had the desired high values for the two traits.

## Introduction

Cassava (*Manihot esculenta* Crantz) has traditionally been grown on a large scale on soils of mineral origin for the starch extraction industry. Whatever limited planting on peat which exists is carried out by small farmers mainly on a subsistence scale. In recent years, there has been interest in exploiting peatland areas (particularly in Sarawak) for the cultivation of cassava. A prerequisite to such plans would be the selection of genotypes which are adapted to peat.

Joseph et al. (1974) and Chew (1977) have reported on the general suitability of peat for cassava cultivation, but until now there has been no systematic study on the stability of yield performance of various cassava genotypes on peat in comparison with mineral soil sites. It is, thus, the purpose of this paper to investigate the stability of two major economic traits, viz. fresh root yield and root starch content, over a range of environments covering both peat and soils of mineral origin.

## Materials and methods

Fifteen cassava genotypes of diverse morphological characteristics were evaluated in a series of trials in 12 environments, i.e. two seasons in each of six locations. While most of the genotypes were advanced selections of seedling clonal origin, three of them (Black Twig, Red Twig and C 5) were varieties previously endorsed by MARDI. Black Twig is also currently the most widely planted commercial variety for starch. The six locations were on mineral soils (Bukit Tangga, Kluang and Serdang) and on peat (Jalan Kebun, Pontian and Teluk Intan). The two planting seasons in each location were at least 6 months apart.

Three of the four agro-ecological zones (AEZ) of Peninsular Malaysia, as defined by Nieuwolt et al. (1982), were represented by the trial locations: Zone 1, distinct dry season of 2–4 months: Bukit Tangga; Zone 2, distinct dry season of 1–2 months: Teluk Intan; Zone 3, no distinct dry season: Kluang, Serdang, Jalan Kebun and Pontian. Zone 4, covering highland areas, was not represented.

Experimental details are given in Tan (1993). Briefly, the trials (over the period August 1986 to June 1989) adopted a randomized complete block design with three replications, and a 4.5 m x 4.5 m sample plot (plant spacing at 0.9 m x 0.9 m) was harvested for data collection. Agronomic practices recommended for cassava on mineral soils (Chan et al. 1983) and on drained peat (Chew 1977; Chew et al. 1978) were adopted. The crop was harvested at 12 months after planting, and data were collected on fresh root yield (plot yield converted to tonnes per hectare) and root starch content [as estimated by specific gravity measurements and converted to percentage of starch by the method of Noor Auni and Tan (1980)].

Combined analyses of variance by location were carried out to gauge the relative importance of genotype, season and genotype x season interaction effects. A random effects model was assumed, and the appropriate tests of significance based on the associated expected mean squares were used for each source of variation. Degrees of freedom for the respective F-ratios were derived from the approximation method suggested by Satterthwaite (1946). A combined analysis of variance on the whole data set was also conducted to detect any statistical difference among the locations.

Subsequently, the stability statistic of Shukla (1972), $\sigma_i^2$, was calculated for each genotype following the equation:

$$\sigma_i^2 = [1/(g-1)(e-1)(e-2)]\ e(e-1) \sum_j (Y_{ij} - Y_{i.} - Y_{.j} + Y_{..})^2 - \sum_i\sum_j (Y_{ij} - Y_{i.} - Y_{.j} + Y_{..})^2$$

where $\sigma_i^2$ = estimate of the stability variance for the $i$th genotype
$g$ = number of genotypes, i.e. 15
$e$ = number of environments, i.e. 12
$Y$ = value of a specific trait, using the usual mathematical notation of genotype and environment

Kang's rank-sum method (Kang 1990; Kang and Pham 1991) was also used to calculate the indices 1–5, where:

Index 1 = trait rank + $\sigma_i^2$ rank
Index 2 = 2(trait rank) + $\sigma_i^2$ rank
Index 3 = 3(trait rank) + $\sigma_i^2$ rank
and so forth.

The non-parametric statistics of Hüh (1979) were also computed:

$$s_i^3 = \sum_j (r_{ij} - \bar{r}_{i.})^2 / \bar{r}_{i.}$$

$$s_i^6 = \sum_j |r_{ij} - \bar{r}_{i.}| / \bar{r}_{i.}$$

where $r_{ij}$ = rank of the $i$th genotype in the $j$th environment
$\bar{r}_i$ = mean of ranks over all environments for the $i$th genotype

Rank correlations were run for all combinations of the statistics: trait rank, $\sigma_i^2$, indices 1–5, $s_i^3$ and $s_i^6$, to gauge their relationships. Ranks were assigned for high (1) to low for the traits, and from low (1) to high for $\sigma_i^2$, $s_i^3$ and $s_i^6$.

## Results and discussion

### *Genotype, season and genotype x season effects*

Analyses of variance over two seasons at each location showed that in the case of fresh root yield, genotype was a significant effect at Serdang, Jalan Kebun and Pontian, while genotype x season (G x S) was significant at Bukit Tangga, Kluang and Pontian. Both these effects were not significant at Teluk Intan *(Table 1)*. The implication is that it would be possible to select for genotypes specifically adapted to five of the locations (with the exception of Teluk Intan) in terms of root yield. Season effect was significant at Kluang, Serdang and Pontian, suggesting that certain seasons in the year favour high yields over others.

In the case of root starch content, the genotype effect was significant at all locations and G x S only at Kluang *(Table 1)*. Thus, selection of genotypes with high starch content is possible in each location. Season effect was significant at Bukit Tangga, Serdang and Pontian, once again implying that certain seasons favour the development of high root starch content.

Nonetheless, the number of seasons tested at each of the locations was only two, a number hardly strong enough as a basis from which to draw solid conclusions on the G x S effect. The above findings, may at best be just an indication of where G x S effects may be important in determining root yield and starch content. Further analyses with trials having more seasons of testing would be required.

### *Overall location and genotype means*

The mean fresh root yields and root starch contents of the 15 genotypes in each of the six locations are presented in *Table 2* and *Table 3* respectively. Looking at overall means, it would appear that the best location for high fresh root yield was Serdang, which had a significantly higher mean than Jalan Kebun and Teluk Intan. Another important point was that Pontian, a peat location, was capable for producing root yields as high as

Table 1. Combined analyses of variance over two seasons in each of the six locations for cassava fresh root yield and root starch content

| Location | Source | df | Mean squares | |
|---|---|---|---|---|
| | | | Root yield | Starch content |
| Bukit | Genotype, G | 14 | 249.89 | 26.59** |
| Tangga | Season, S | 1 | 138.89 | 140.11* |
| | Rep. within S | 4 | 45.36 | 11.98 |
| | G x S | 14 | 222.28* | 5.91 |
| | Error | 56 | 109.21 | 7.30 |
| Kluang | Genotype | 14 | 220.38 | 18.68* |
| | Season, S | 1 | 3 333.70** | 14.91 |
| | Rep. within S | 4 | 127.03 | 2.22 |
| | G x S | 14 | 166.71* | 6.81* |
| | Error | 56 | 82.67 | 3.44 |
| Serdang | Genotype | 14 | 297.35** | 17.09** |
| | Season, S | 1 | 701.18* | 33.75** |
| | Rep. within S | 4 | 47.81 | 1.77 |
| | G x S | 14 | 58.33 | 1.20 |
| | Error | 56 | 55.94 | 1.02 |
| Jalan | Genotype | 14 | 266.47** | 24.45** |
| Kebun | Season, S | 1 | 37.79 | 0.63 |
| | Rep. within S | 4 | 809.74** | 12.30** |
| | G x S | 14 | 53.07 | 1.71 |
| | Error | 56 | 41.05 | 1.73 |
| Pontian | Genotype | 14 | 343.51** | 29.18** |
| | Season, S | 1 | 4 189.86** | 106.75** |
| | Rep. within S | 4 | 9.50 | 3.50 |
| | G x S | 14 | 57.75** | 3.00 |
| | Error | 56 | 18.51 | 2.42 |
| Teluk | Genotype | 14 | 272.50 | 27.29** |
| Intan | Season, S | 1 | 414.46 | 6.88 |
| | Rep. within S | 4 | 173.62 | 3.33 |
| | G x S | 14 | 143.79 | 2.25 |
| | Error | 56 | 98.91 | 1.70 |

*, ** variance ratio significant at 0.05 and 0.01 probability respectively

those at Serdang, a mineral soil location. It was also interesting to note that Bukit Tangga, located in AEZ 1, was also high yielding despite the presence of 2–4 months per year of agricultural drought. It would appear that timing of planting was important to avoid an impending drought period which would jeopardize good crop establishment.

The highest genotype mean (over the six locations) was from CM 982-7. At a mean root yield of 47.2 t/ha, it was close to 40% higher yielding than Black Twig and 80% higher than Red Twig, the two commercial varieties. Indeed, Red Twig was among the lowest yielding genotypes (<30 t/ha), the others being CM 845-13, CM 305-8 and M Mex 1-20.

In the case of root starch content, the best location was also Serdang, closely followed by Bukit Tangga. Although it appears that the peat locations generally produced lower root starch contents than the mineral soil locations, the value at Jalan Kebun was not significantly different from that of Kluang. Genotypes with the highest overall means for starch content (> 25%)

Table 2. Location means and genotypic means for fresh root yield

| Genotype | Fresh root yield (t/ha) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Bukit Tangga | Kluang | Serdang | Jalan Kebun | Pontian | Teluk Intan | Mean |
| Black Twig | 38.3 | 29.7 | 35.9 | 26.2 | 31.9 | 42.0 | 34.0 |
| Red Twig | 33.2 | 21.7 | 28.4 | 21.0 | 22.9 | 29.9 | 26.2 |
| C 5 | 30.4 | 37.4 | 32.6 | 23.3 | 32.9 | 24.6 | 30.2 |
| CM 305-8 | 22.1 | 27.8 | 39.0 | 26.1 | 26.5 | 29.0 | 28.4 |
| CM 378-17 | 32.4 | 33.9 | 33.9 | 23.5 | 35.3 | 21.2 | 30.0 |
| CM 621-7 | 27.6 | 42.7 | 41.9 | 36.3 | 44.2 | 33.6 | 37.7 |
| CM 621-22 | 36.3 | 34.8 | 38.9 | 24.6 | 39.7 | 27.5 | 33.6 |
| CM 621-42 | 36.1 | 36.7 | 47.4 | 28.4 | 36.1 | 23.3 | 34.7 |
| CM 845-13 | 28.0 | 27.4 | 32.2 | 23.2 | 28.3 | 22.8 | 27.0 |
| CM 942-28 | 31.6 | 37.1 | 43.0 | 27.9 | 35.3 | 28.5 | 33.9 |
| CM 982-2 | 27.8 | 31.6 | 28.6 | 33.0 | 41.7 | 28.5 | 31.9 |
| CM 982-7 | 49.8 | 42.8 | 52.6 | 46.6 | 52.5 | 38.7 | 47.2 |
| M Mex 1-20 | 29.8 | 26.4 | 33.0 | 30.0 | 29.8 | 27.2 | 29.4 |
| 17/A | 41.6 | 32.7 | 36.5 | 23.4 | 34.6 | 43.2 | 35.3 |
| CM 462-6 | 35.1 | 38.5 | 45.7 | 23.0 | 41.6 | 27.3 | 35.2 |
| Mean | 34.8ab | 33.4ab | 38.0a | 27.8b | 35.6a | 29.8b | |
| C.V. (%) | 30.0 | 27.2 | 19.7 | 23.1 | 12.1 | 33.4 | |
| LSD ($p \leq 0.05$) | 17.1 | 14.8 | 12.2 | 10.5 | 7.0 | 16.2 | |

Note: Location means with the same letter are not significantly different from one another according to the LSD test at the 0.05 probability level

Table 3. Location means and genotypic means for root starch content

| Genotype | Root starch content (%) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Bukit Tangga | Kluang | Serdang | Jalan Kebun | Pontian | Teluk Intan | Mean |
| Black Twig | 24.9 | 24.8 | 26.8 | 24.6 | 24.4 | 22.8 | 24.9 |
| Red Twig | 26.7 | 25.6 | 27.2 | 24.8 | 24.0 | 23.8 | 25.4 |
| C 5 | 25.2 | 22.3 | 25.2 | 22.8 | 22.4 | 22.7 | 23.6 |
| CM 305-8 | 22.6 | 22.1 | 25.2 | 20.8 | 19.9 | 18.8 | 21.6 |
| CM 378-17 | 26.1 | 26.5 | 26.9 | 22.9 | 23.4 | 22.7 | 24.8 |
| CM 621-7 | 20.8 | 22.2 | 25.8 | 21.5 | 21.5 | 21.5 | 22.7 |
| CM 621-22 | 23.3 | 24.4 | 23.4 | 21.1 | 21.4 | 21.5 | 22.5 |
| CM 621-42 | 23.6 | 23.7 | 25.5 | 23.1 | 23.1 | 22.1 | 23.9 |
| CM 845-13 | 25.6 | 27.6 | 27.8 | 24.8 | 24.6 | 25.0 | 25.8 |
| CM 942-28 | 23.5 | 24.2 | 25.5 | 23.4 | 22.7 | 22.2 | 23.7 |
| CM 982-2 | 24.7 | 23.6 | 26.3 | 24.2 | 23.6 | 23.8 | 24.7 |
| CM 982-7 | 22.2 | 22.8 | 23.4 | 19.8 | 20.2 | 19.0 | 21.5 |
| M Mex 1-20 | 27.6 | 25.0 | 26.8 | 25.1 | 23.9 | 25.3 | 25.5 |
| 17/A | 25.1 | 25.1 | 27.1 | 23.7 | 22.9 | 23.2 | 24.4 |
| CM 462-6 | 20.2 | 21.2 | 21.8 | 18.3 | 16.2 | 18.1 | 20.0 |
| Mean | 25.2ab | 24.0bc | 25.6a | 22.7cd | 22.3d | 22.2d | |
| C.V. (%) | 11.2 | 7.7 | 3.9 | 5.8 | 7.0 | 5.9 | |
| LSD ($p \leq 0.05$) | 4.4 | 3.0 | 1.6 | 2.2 | 2.5 | 2.1 | |

Note: Location means with the same letter are not significantly different from one another according to the LSD test at the 0.05 probability level included CM 845-13, M Mex 1-20 and Red Twig, the same three genotypes with the lowest overall fresh root yields. The lowest starch contents were recorded in CM 462-6, CM 982-7 and CM 305-8. Black Twig, together with CM 378-17, CM 982-2 and 17/A, showed reasonable contents in starch in the vicinity of 24%.

***Performance by location***

**Bukit Tangga (mineral soil, AEZ 1)** CM 982-7 produced the highest root yield, followed by 17/A, Black Twig, CM 621-22, CM 621-42, CM 462-6 and Red Twig, the root yields of which were not significantly different. Although root starch content was highest in M Mex 1-20, the value was not significantly different from those of all the high-yielding genotypes except CM 982-7 and CM 462-6.

Thus, it would seem that the best genotypes for this particular location based on the two traits would be 17/A, Black Twig, Red Twig, CM 621-22 and CM 621-42.

**Kluang (mineral soil, AEZ 3)** Again CM 982-7 was the highest yielding genotype, followed by CM 621-7, CM 462-6, C 5, CM 942-28, CM 621-42 and five others (including Black Twig). In the case of root starch content, the best genotypes in this location were CM 845-13, CM 378-17, Red Twig, 17/A, M Mex 1-20 and Black Twig.

In this location, Black Twig and 17/A (one of the genotypes with a root yield not significantly different from that of CM 982-7) would be better suited for starch yield production.

**Serdang (mineral soil, AEZ 3)** The top five genotypes for fresh root yield (with no significant differences amongst them) were CM 982-7, CM 621-42, CM 462-6, CM 942-28 and CM 621-7. The yield of CM 982-7 was significantly higher than that of the current commercial variety Black Twig. At this location, starch contents were highest in CM 845-13, Red Twig, 17/A, CM 378-17, Black Twig, M Mex 1-20 and CM 982-2. Unfortunately, none of the two lists tally.

For Serdang, the best combination of moderately high yield and high starch content was to be found in 17/A and Black Twig.

**Jalan Kebun (peat, AEZ 3)** At Jalan Kebun, CM 982-7 had a significantly higher root yield than Black Twig, followed by CM 621-7. For starch content, however, the best genotypes were M Mex 1-20, Red Twig, CM 845-13, Black Twig, CM 982-2, 17/A, CM 942-28 and CM 621-42. Again, the genotypes in the two lists do not tally.

A compromise may be sought in CM 982-2, M Mex 1-20 and CM 621-42.

**Pontian (peat, AEZ 3)** CM 982-7 produced the significantly highest root yield of all the other genotypes at Pontian. However, as with the other locations, this genotype is not outstanding in its root starch content. Others with root yields significantly higher than Black Twig's were CM 621-7, CM 982-2, CM 464-6 and CM 621-22. The highest starch contents were in CM 845-13, Black Twig, Red Twig, M Mex 1-20, CM 982-2, CM 378-17, CM 621-42, 17/A, CM 942-28 and C 5.

Here, a compromise may be found in CM 982-2, CM 621-42 and CM 942-28.

**Teluk Intan (peat, AEZ 2)** Unlike in the other locations, the highest yielder at Teluk Intan was 17/A, followed by Black Twig, CM 982-7, CM 621-7, Red Twig, CM 305-8 and five others. Starch content was highest in M Mex 1-20, CM 845-13 (both significantly more than Black Twig), Red Twig, CM 982-2 and 17/A.

Thus, the best genotypes for Teluk Intan may be 17/A, Red Twig, M Mex 1-20 and CM 982-2.

**General and specific adaptation** For high root yield alone, CM 982-7 is most widely adapted to all locations, irrespective of soil type or agro-ecological zone. However, taking both high root yield and high starch content into consideration, it would seem that certain genotypes are specifically adapted to mineral soils, peat and the agro-ecological zones respectively, i.e.

- Mineral soils : 17/A, Black Twig
- Drained peat : CM 982-2
- AEZ 1 : Red Twig, CM 621-22, CM 621-42
- AEZ 2 : Red Twig, M Mex 1-20, CM 982-2
- AEZ 3 : none specifically

***Stability***

The concept of stability was introduced by Lerner (1954) using the term homeostasis. This according to Becker (1981) is the 'biological' concept, implying a lack to response by a particular genotype to a range of environments. Hence, using Shukla's (1972) stability variance, the smaller the value of $\sigma_i^2$, the more stable is the genotype. Becker postulated that the 'agronomic' type of stability is to be preferred because it indicates a positive response of a genotype to better environments. Thus, in the latter case, genotype x environment interactions will be detected but they will not change the ranking of a group of genotypes in different environments. Hüh's (1979) statistics help in discerning the magnitude of any changes in rank order. In short, the smaller the values of $s_i^3$ and $s_i^6$, the more stable is the genotype in question.

Significant genotype x environment interactions had been detected for both fresh root yield and root starch content by Tan (1993). Genotype means over replications were calculated for each environment (trial), and ranks were assigned for overall means (highest receiving rank of 1) as well as for $\sigma_i^2$ (lowest receiving rank of 1).

For root yield *(Table 4)*, Hüh's non-parametric statistics $s_i^3$ and $s_i^6$ were found to be significantly correlated with Shukla's stability variance $\sigma_i^2$ and negatively correlated with yield itself. $s_i^6$ was also negatively correlated with Kang's rank-sum indices 3, 4 and 5. All the rank-sum indices (1–5) were highly correlated with one another. It should be remembered that index 1 assigned equal weights to yield and the stability variance $\sigma_i^2$, whereas in index 2, yield was assigned twice the weight of $\sigma_i^2$, and so forth for indices 3 to 5.

For starch content *(Table 5)*, $s_i^3$ was correlated with $\sigma_i^2$, while $s_i^6$ was negatively correlated with starch content. Negative correlations were also found between $s_i^6$ and the rank-sum indices 2, 3, 4 and 5. As in the case of root yield, all the rank-sum indices were highly correlated with one another.

Thus, in terms of general adaptability and stability of root yield, the outstanding genotypes were Black Twig and CM 942-28

Table 4. Rank-correlation coefficients among stability-variance ($\sigma_i^2$), root yield, rank-sum indices and Hün's non-parametric statistics $s_i^3$ and $s_i^6$

| | Yield | Index 1 | Index 2 | Index 3 | Index 4 | Index 5 | $s_i^3$ | $s_i^6$ |
|---|---|---|---|---|---|---|---|---|
| $\sigma_i^2$ | –0.44 | 0.52* | 0.06 | –0.12 | –0.21 | –0.26 | 0.90** | 0.72** |
| Yield | | 0.53* | 0.87** | 0.94** | 0.97** | 0.98 ** | –0.63* | –0.81** |
| Index 1 | | | 0.88** | 0.78** | 0.72** | 0.68 ** | 0.25 | –0.09 |
| Index 2 | | | | 0.98** | 0.96** | 0.95** | 0.20 | –0.50 |
| Index 3 | | | | | 1.00** | 0.99** | –0.37 | –0.63** |
| Index 4 | | | | | | 1.00** | –0.44 | –0.69** |
| Index 5 | | | | | | | –0.48 | –0.72** |
| $s_i^3$ | | | | | | | | 0.86 ** |

*, **significant at the 0.05 and 0.01 probability levels respectively

Table 5. Rank-correlation coefficients among stability-variance ($\sigma_i^2$), starch content, rank-sum indices and Hühn’s non-parametric statistics $s_i^3$ and $s_i^6$

| | Starch | Index 1 | Index 2 | Index 3 | Index 4 | Index 5 | $s_i^3$ | $s_i^6$ |
|---|---|---|---|---|---|---|---|---|
| $\sigma_i^2$ | 0.29 | 0.80* | 0.63** | 0.54* | 0.49 | 0.45 | 0.58* | 0.17 |
| Starch | | 0.80** | 0.92** | 0.96** | 0.98** | 0.98** | –0.51 | –0.86** |
| Index 1 | | | 0.97** | 0.94** | 0.91** | 0.90 ** | 0.04 | –0.43 |
| Index 2 | | | | 0.99** | 0.98** | 0.98** | –0.18 | –0.62* |
| Index 3 | | | | | 1.00** | 1.00** | –0.28 | –0.70** |
| Index 4 | | | | | | 1.00** | –0.33 | –0.74** |
| Index 5 | | | | | | | –0.37 | –0.77** |
| $s_i^3$ | | | | | | | | 0.86** |

*, ** significant at the 0.05 and 0.01 probability levels respectively

Table 6. Mean yield, stability variance ($\sigma_i^2$), rankings according to root yield and five rank-sum indices, $s_i^3$ and $s_i^6$

| Genotype | Yield | $\sigma_i^2$ | Rank-sum | | | | | $s_i^3$ | $s_i^6$ |
|---|---|---|---|---|---|---|---|---|---|
| | | | Index 1 | Index 2 | Index 3 | Index 4 | Index 5 | | |
| Black Twig | 34.0 | 47.21 | 15 | 21 | 27 | 33 | 39 | 18.79 | 4.76 |
| Red Twig | 26.2 | 31.55 | 20 | 35 | 50 | 65 | 80 | 10.17 | 2.96 |
| C 5 | 30.2 | 33.20 | 17 | 28 | 39 | 50 | 61 | 14.43 | 3.36 |
| CM 305-8 | 32.1 | 61.39 | 20 | 29 | 38 | 47 | 56 | 23.70 | 5.43 |
| CM 378-17 | 30.0 | 61.55 | 24 | 36 | 48 | 60 | 72 | 21.74 | 4.71 |
| CM 621-7 | 37.7 | 57.06 | 12 | 14 | 16 | 18 | 20 | 33.64 | 7.35 |
| CM 621-22 | 33.6 | 12.28 | 10 | 18 | 26 | 34 | 42 | 10.19 | 3.55 |
| CM 621-42 | 34.7 | 43.77 | 12 | 17 | 22 | 27 | 32 | 20.74 | 4.98 |
| CM 845-13 | 27.0 | 12.22 | 15 | 29 | 43 | 57 | 71 | 5.51 | 1.84 |
| CM 942-28 | 33.9 | 12.35 | 10 | 17 | 24 | 31 | 38 | 7.13 | 3.06 |
| CM 982-2 | 31.9 | 65.04 | 23 | 33 | 43 | 53 | 63 | 24.13 | 5.14 |
| CM 982-7 | 47.2 | 46.41 | 9 | 10 | 11 | 12 | 13 | 20.58 | 8.19 |
| M Mex 1-20 | 29.4 | 27.16 | 17 | 30 | 43 | 56 | 69 | 12.19 | 2.96 |
| 17/A | 35.3 | 89.62 | 17 | 20 | 23 | 26 | 29 | 27.87 | 5.47 |
| CM 462-6 | 35.2 | 107.55 | 19 | 23 | 27 | 31 | 35 | 39.71 | 7.71 |

Note: Underlined values indicate genotypes selected

*(Table 6)* which would be selected by any of the parameters. On the bases of high overall yield as well as the rank-sum indices, CM 621-7, CM 621-42 and CM 982-7 would also be selected. Hühn’s parameters would also have selected Red Twig, C 5, CM 621-22, CM 845-13 and M Mex 1-20 for stability of yield, but these genotypes are by no means among the highest yielders. This was due to the negative correlations these parameters had with yield *(Table 4)*.

For general stability of high root starch content, genotypes superior in this respect were Black Twig, Red Twig and CM 378-17 since all the parameters except $s_i^6$ were in agreement *(Table 7)*. Based on high mean starch content and the rank-sum indices, CM 845-13, CM 982-2, M Mex 1-20 and 17/A would also be selected. Both Hühn’s parameters picked out C 5, CM 621-22, CM 942-28 and CM 982-7. Unfortunately, these genotypes tended to be stable for low to moderate starch contents, again because of the negative association of $s_i^6$ with starch content.

Thus, the genotype with stability in both moderately high fresh root yield and root starch content would be Black Twig. This variety, already the most widely cultivated in the country to supply root for

Table 7. Mean root starch content, stability variance ($\sigma_i^2$), rankings according to starch content and five rank-sum indices, $s_i^3$ and $s_i^6$

| Genotype | Starch | $\sigma_i^2$ | Rank-sum | | | | | $s_i^3$ | $s_i^6$ |
|---|---|---|---|---|---|---|---|---|---|
| | | | Index 1 | Index 2 | Index 3 | Index 4 | Index 5 | | |
| Black Twig | 24.9 | 0.69 | 6 | 10 | 14 | 18 | 22 | 9.71 | 3.92 |
| Red Twig | 25.4 | 0.77 | 6 | 9 | 12 | 15 | 18 | 8.08 | 3.85 |
| C 5 | 23.6 | 1.19 | 18 | 28 | 38 | 48 | 58 | 6.75 | 2.50 |
| CM 305-8 | 21.6 | 1.27 | 22 | 35 | 48 | 61 | 74 | 13.24 | 2.86 |
| CM 378-17 | 24.8 | 0.81 | 9 | 14 | 19 | 24 | 29 | 9.24 | 4.10 |
| CM 621-7 | 22.7 | 2.70 | 24 | 35 | 46 | 57 | 68 | 13.05 | 3.45 |
| CM 621-22 | 22.5 | 2.42 | 24 | 36 | 48 | 60 | 72 | 9.12 | 2.10 |
| CM 621-42 | 23.9 | 1.38 | 18 | 26 | 34 | 42 | 50 | 13.69 | 4.15 |
| CM 845-13 | 25.8 | 3.64 | 15 | 16 | 17 | 18 | 19 | 23.61 | 7.49 |
| CM 942-28 | 23.7 | 0.45 | 10 | 19 | 28 | 37 | 46 | 5.04 | 2.18 |
| CM 982-2 | 24.7 | 0.94 | 12 | 18 | 24 | 30 | 36 | 9.99 | 4.14 |
| CM 982-7 | 21.5 | 1.12 | 21 | 35 | 49 | 63 | 77 | 1.44 | 1.02 |
| M Mex 1-20 | 25.5 | 2.10 | 13 | 15 | 17 | 19 | 21 | 21.43 | 6.57 |
| 17/A | 24.4 | 0.85 | 12 | 19 | 26 | 33 | 40 | 11.67 | 4.00 |
| CM 462-6 | 20.0 | 5.84 | 30 | 45 | 60 | 75 | 90 | 11.83 | 1.83 |

Note: Underlined values indicate genotypes selected

starch extraction, may therefore be recommended for practically any location in Peninsular Malaysia.

## General conclusions

While Black Twig may be the most widely adapted (and stable) genotype for both yield and starch content, it is important to recognise specific adaptability (as suggested by the existence of significant genotype x environment interactions) as being also important. As discussed earlier, it was possible to select certain genotypes for mineral soils or for drained peat in general, as well as for AEZ 1 and AEZ 2, which will promise both reasonable yield combined with moderately high starch content.

Although the main cassava-based industry at present is starch extraction (for which reason, the above conclusions were drawn), there also exists a parallel albeit smaller market for edible cassava. For this latter market, starch content is much less important. Instead, there should be greater awareness of root cyanide content, in order that only genotypes with 'safe' levels of cyanide are sold for eating. Thus, by not considering starch content, and concentrating on high fresh yield *per se*, the most widely adapted genotype (to both soil type and agro-ecological zoning) would be CM 982-7, considered stable by the rank-sum indices. Also well-adapted to mineral soils was CM 462-6, and to a lesser extent CM 621-22 and CM 621-42, whereas for drained peat, CM 621-7 may be considered to be adapted to this medium as well. Both AEZ 1 and AEZ 2 shared in common the genotypes 17/A, Black Twig and Red Twig for high root yield.

It is interesting to note that of these genotypes, those considered to have low to moderately low cyanide contents are CM 462-6, CM 621-7, CM 982-7 and CM 621-22 (Tan 1993), and are therefore suitable as edible types. Black Twig (Chan et al. 1983) and Red Twig (Tan 1993) on the other hand, being starch varieties with high root cyanide contents, are considered non-edible.

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