ASSESSING THE POSSIBILITY OF MISLABELLING ERRORS IN RANDOMLY SAMPLED GRAFTED COCOA SEEDLINGS FROM TEN COCOA NURSERIES IN SABAH USING THE KOKOCORRECT™

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ABSTRACT – *Cocoa nurseries play a crucial role in providing high-quality planting materials for cocoa planting. As mislabelling and misidentification of cocoa clones can lead to adverse effects on genetic diversity, productivity, and pest and disease tolerance, the study was embarked on to evaluate mislabelling errors in grafted cocoa seedlings from ten cocoa nurseries in Sabah, Malaysia. At the same time, the study also evaluated the usefulness of the KokoCorrect™ molecular bio-diagnostic kit for clone identification in grafted cocoa seedlings. A total of 1,367 grafted cocoa seedlings were genotyped using the KokoCorrect™, which utilizes a set of ten single nucleotide polymorphism (SNP) markers. The results revealed extensive mislabelling and misidentification, especially in nurseries that did not tag seedlings with clone names. Out of the total samples, 6.7% were identified as non-commercial or unknown clones, indicating errors in scions source selection during the grafting process and mislabelling error rate ranging from 12.5% to 92.5% were observed. The KokoCorrect™ kit effectively distinguished mislabelled grafted cocoa seedlings and provided accurate clone identification. The findings underscore the need for standardized procedures in cocoa nurseries to ensure accurate labelling and identity of planting materials. The study also highlighted the significance of proper training, standard operating procedures, and improved labelling practices to mitigate mislabelling errors. The use of the KokoCorrect™ kit offers a reliable and cost-effective solution for clonal identification, enabling efficient screening of large numbers of cocoa planting materials. This research emphasizes the importance of maintaining clonal integrity in cocoa cultivation to enhance productivity and sustainability*.

Keywords: Mislabelling error, grafted cocoa seedlings, cocoa nurseries, genotyping

INTRODUCTION

Cocoa (*Theobroma cacao* L.) is the most important ingredient when it comes to the processing of chocolate and cocoa-based products. As a tropical forest species native to the South American continent, cocoa is one of the significant segment of the global agriculture, and substantial economics contributor (Aikpokpodion, 2011). As the primary and irreplaceable ingredient of chocolate and chocolate-based products, cocoa is a significant commodity in the chocolate and confectionery industries despite being only a small soft commodity. The cultivation of cocoa is one of the most important commodities in Malaysia, mostly planted by smallholders which make up to 89% of cultivation areas (Malaysian Cocoa Board, 2023).

Malaysia used to be the third largest producer of cocoa in the world in 1990, but due to rapid increase of demand, inherent use of poor planting materials, inefficient pest and disease management and poor technology utilisation has caused the decrease on cocoa planting in Malaysia. The total cocoa planting acreage in Malaysia amounted to 5,985 hectares in 2022, with exports amounting to RM 7.8 billion (Malaysian Cocoa Board, 2023). As a strategy to overcome the inherent problem of poor planting materials, the Malaysian Cocoa Board has developed, evaluated, and selected 53 locally developed cocoa clones recommended as the cocoa planting materials for cocoa planting. These 53 locally selected superior cocoa clones are divided into 4 classes: Class I, Class II, Class III and Class IV with regards to yield, pest and diseases, fat content etc., and adaptability to various Malaysian agro-climatic conditions (Aizat *et al*., 2020).

Cocoa is an outcrossing species (Wood and Lass, 1985) and germplasm is conserved as clonally propagated trees in field genebanks. Cocoa collections

have also been shown to exhibit some variety of mislabelled individuals in many cocoa germplasm collections (Motilal and Butler, 2003; Sounigo *et al*., 2006, Irish *et al*., 2010, Boza *et al*., 2013). A mislabelling occurrence can be due to frequent introduction and transfers of plants from point-of-collection to early holding sites, the subsequent recollection of budwood, and repropagation of materials for planting materials distribution to farmers' fields. Another factor in the mislabelling issues is human errors during selection of explant for propagation, assessment of plant accessions' phenotypically, loss of plant labels, misreading of germplasm labels *etc*. (Irish *et al*., 2010, Boza *et al*., 2013). Misidentification of plants can also occur as a result of environmental effects and agronomic inputs which can slightly change the colour, size, shape etc of the plant. Thus, an accurate and reliable clonal identification method is crucial for various purposes, such as breeding programs, establishment and maintenance of elite clones and genetic diversity.

Planting materials of high quality and the use of genetically pure bred are prerequisites to the success of any crop agricultural system. Malaysian Cocoa Board has carried out activities in the breeding program since 1992, purposely to develop superior planting material for cocoa. At the cocoa nursery, cocoa is typically propagated as seedlings and grafted with chosen clonal scions from the mother plants. Grafted cocoa seedlings are one of the easiest and simplest planting materials to produce clonal seedlings for planting in the farms. The source of scions used for grafting in nurseries ultimately affects the cocoa adult trees' potential yield, tolerance to pest and disease and agro-climatic conditions (Malaysian Cocoa Board, 2013).

The current common practice of cocoa seedlings/nursery entrepreneurs is taking grafting (scions) source materials from farmer fields in which trees were not verified or validated to be clean from homonymous or synonymous errors. Errors in the mother plant (source of grafting materials) would cause a massive error in the seedlings distributed to the farmers for new planting in the field. Mislabelling can cause the inability of the farmer fields to achieve the expected yield potential of the selected clones used in the fields, thereby it is crucial to know the exact variety of the plants to be used as mother plants or scions' source. Identification and verification of variety should not be performed by just looking at the phenotypic characteristics of the plants as phenotypic characteristics are environmental conditions dependence. A plant that looks like one specific variety does not mean that it will perform like that variety. Moreover, most of the Malaysian selected cocoa planting materials were developed from the same parental clones or closely related. To keep cocoa clone true to type, propagators must be sure of the plant variety before they propagate it.

To address the issue of mislabelling in plant propagation, several strategies should be implemented such as prioritizing accurate labelling and identity of the plant during propagation process which can be done by proper training and setting suitable standard operating procedures for planting materials propagation. Due to the difficulty of differentiating cocoa clones through phenotypic traits, molecular markers have been recently employed in the identification and verification of plant materials (Guiltinan *et al*., 2008).

Malaysian Cocoa Board has set up a small set of single nucleotide polymorphisms (SNPs) for the development of identification and verification kit specially for the 53 Malaysian cocoa clones (Johnsiul *et al*., 2022). This set of ten SNP markers collectively is referred as KokoCorrect™ and it is based on a multi-locus SNP reference profiles. The use of KokoCorrect™ has been evaluated in identification of the Malaysian cocoa clones collection (Johnsiul *et al*., 2022). The small number of markers used has helped to reduce cost of clonal identification through molecular markers and can be automated in screening large numbers of Malaysia cocoa planting materials.

Observations done at farmers' farms and information from farmers indicated planting materials distributed to the farmers sometimes exhibited different characteristics or traits from the expected clones which suspected to be the result of some mislabelling / misidentification of the grafted cocoa seedlings clonal identities that have occurred in the nurseries. Based on observations at cocoa nurseries, there is no specific standard operating procedures required to monitor / inspect the accuracy of the sources of explants used in the planting materials propagation or the identity of the grafted cocoa seedlings distributed to the farmers' farms. Thus, the objectives of this work are to evaluate KokoCorrect™ usefulness in identifying and verifying a small proportion representative of the grafted cocoa seedlings and to assess the possibility of mislabeling errors occurring in the grafted cocoa seedlings production from cocoa nurseries from selected cocoa nurseries in Sabah.

MATERIALS AND METHODS

Samples collection

One thousand three hundreds and sixty-seven grafted cocoa seedlings were collected from ten cocoa

nurseries in Kota Marudu, Keningau and Ranau were sampled. These ten nurseries were grafted cocoa seedlings distributors for the cocoa farms around Sabah (Table 1). Five leaf discs were collected from each individual grafted cocoa seedlings. DNA extraction was performed using the LGC DNA extraction service (https://www.biosearchtech.com).

SNP Genotyping

All the one thousand three hundreds and sixty seven DNA were SNP genotyped using the KokoCorrect™ molecular bio diagnostic kit to generate DNA fingerprint profiles. SNP genotyping was performed using KASP™ assays from LGC Genomics (http://www.lgcgroup.com/kasp). KASP genotyping assays are based on competitive, allele-specific PCR and enable high-throughput genotyping of specific SNPs. Once the KASP™ reaction was completed, the resulting fluorescence was measured on a BMG PHERAstar plate reader. The raw data were analysed using LGC's proprietary Kraken™ software and scored on a Cartesian plot, also known as a cluster plot, in order to assign a fingerprint profile to each DNA sample.

Table 1: List of Nursery names, cocoa clones and the number of grafted cocoa seedlings collected from each cocoa nursery.

No.	Nursery Name	Samples Collection
1	MU, Kg. Tambiau, Ranau	147 grafted cocoa seedlings without no clone name tag.
2	MK, Kg. Sodul, Ranau	125 grafted cocoa seedlings without no clone name tag.
3	KB, Kg. Waang, Ranau	125 grafted cocoa seedlings without no clone name tag.
4	JK, Kg Togis, Ranau	75 grafted cocoa seedlings with clone BR25 tagging. 75 grafted cocoa seedlings with clone KM22 tagging
5	BB, Kg Tambiau, Ranau	201 grafted cocoa seedlings with clone MCBC8 tagging
6	MG, Kg Goshen, Kota Marudu	95 grafted cocoa seedlings without no clone name tag.
7	AG, Kg. Goshen Tagaroh, Kota Marudu	100 grafted cocoa seedlings without no clone name tag.
8	MD, Ranau	100 grafted cocoa seedlings without no clone name tag.
9	RB, Keningau	87 grafted cocoa seedlings without no clone name tag.
10	CC, Ranau	40 grafted cocoa seedlings with clone PBC123 tagging. 39 grafted cocoa seedlings with clone MCBC1 tagging. 40 grafted cocoa seedlings with clone BR25 tagging. 38 grafted cocoa seedlings with clone QH1003 tagging. 40 grafted cocoa seedlings with clone MCBC8 tagging. 40 grafted cocoa seedlings with clone KKM22 tagging.

Data analysis

The quality of the data was evaluated by reviewing the SNP clustering from each locus in SNPViewer. All ambiguous data points were removed before further processing and treated as "missing data" which is a standard approach and does not impact on the major results and conclusions given the high quality of the remaining data.

Raw data was imported and organized in Microsoft Excel for each of the SNP locus and sample calls. The approach used to identify mislabelling (off-types) in the collection was to directly compare the reference clones fingerprint profiles with the genotyped samples. Samples with non-matching SNP patterns with the reference were considered off-types.

RESULTS

Multilocus Matching

A total of 1,367 randomly sampled grafted cocoa seedlings from ten different cocoa nurseries in Sabah were assessed using the KokoCorrect™ molecular bio diagnostic kit. The expected clones were identified based on nursery owners' information through the seedlings' taggings (when available), while the observed genotypes were determined using the KokoCorrect™ kit.

A stringent scoring was applied where all loci were required to match with reference profiles before

being considered as true to type. Results of the KokoCorrect™ on all the samples were shown in Table 2. Out of ten cocoa nurseries, only 3 cocoa nurseries have tagged their seedlings with the clone names and 7 did not tagged their seedlings with any clone name. For seedlings samples with clone name tagging, the mislabelling errors were determined for the seedling samples with clone name tagging, however using KokoCorrect™, the correct clones were identified (Table 2). The distribution of seedling samples according to classes of Malaysian cocoa clones is shown in Figure 1. The mislabelling error rates for samples from the 3 cocoa nurseries ranged from 0% to 92.5% (Figure 2).

The results indicated that there were significant differences between expected and observed genotypes across the sample population. This can be observed clearly in the results of the three nurseries where clone name tags were applied to the grafted cocoa seedlings (Figure 2). Figure 2 revealed extensive mislabelling and misidentification of the sampled seedlings. Out of the 150 grafted cocoa seedlings from JK's nursery labelled as KKM22 and BR25, 32 were misidentified: 30 trees labelled as KKM22 were found to be BR25, and 2 trees labelled as BR25 were analysed as KKM22. Similarly, in BB's nursery, 59 out of 201 grafted seedlings labelled as MCBC8 were identified as different clones (Table 2).

Across the ten nurseries, a total of 91 samples, or 6.7% of the total, were identified as non-commercial or unknown clones. These samples could not be matched to any of the commercial Malaysian cocoa clones using the KokoCorrect™ kit, suggesting that they may represent a different genetic background and errors in the grafting process.

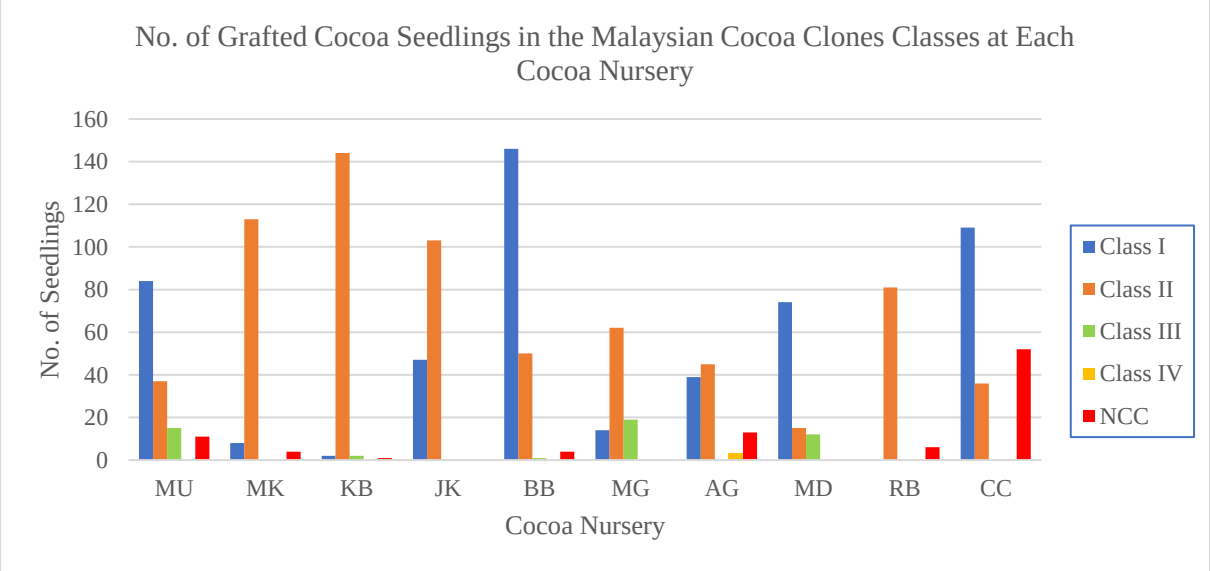

Figure 1: The distribution of grafted cocoa seedling samples according to the classes of the Malaysian cocoa clones

DISCUSSION

The mislabelling and misidentification of cocoa clones can potentially lead to numerous negative effects in genetic diversity, productivity and pest and disease tolerance. The mixing of unwanted clones with the high-quality clones due to misidentification and mislabelling, could result in the propagation of cocoa which are less productive, with undesirable agronomic traits and pest and diseases susceptibility. As the consequences, this could reduce overall productivity and increase susceptibility of cocoa crops to pest and disease, eventually could jeopardize the long-term sustainability of the cocoa industry.

The Malaysian cocoa clones are a selection of cocoa clones recommended for planting by the MCB Cocoa Breeding Program which conducted research and developed planting materials that have desirable agronomic traits such as high yield potential, suitable for planting under various environmental conditions, tolerant to major pest and disease, high butterfat content, good flavour, low pod index and good bean sizes (Aizat *et al.*, 2020). The Malaysia Cocoa Clones

are categorized into four classes based on their suitability for planting in throughout, yield potential, pod, and bean quality and tolerant to major pest and diseases. Based on information gathered from the

Table 2: The results of KokoCorrect™ analyses on all 1367 samples from the 10 cocoa nurseries in Sabah.

No	Nursery ID	Expected Clones	Identified Clones	Comments
1	MU, Kg. Tambiau, Ranau	147 grafted cocoa seedlings without No Clone Name Tag.	MCB C8 (32), MCB C10 (1), MCB C1(5) QH1003 (3), PBC 123 (9), KKM 22 (34) MCB C9 (3), BR 25 (15), KKM 25 (2) KKM 1(17) QH 1176 (9), MCB C2 (6) Non-Commercial clone – 11 trees	Out of 147 grafted cocoa seedlings, 84 trees are from Class I, 37 trees are from Class II, 15 from Class III and 11 trees are non-Malaysia commercial cocoa clones.
2	MK, Kg. Sodul, Ranau	125 grafted cocoa seedlings without No Clone Name Tag.	KKM 22 (1), PBC 123 (7) KKM 25 (2), BR 25 (111) Non-Commercial clone – 4 trees	Out of 125 grafted cocoa seedlings, 8 trees are from Class I, 113 trees are from Class II and 4 trees are non- Malaysia commercial cocoa clones.
3	KB, Kg. Waang, Ranau	125 grafted cocoa seedlings without No Clone Name Tag.	QH 1003(2) BR 25 (144) MCB C2 (2) Non-Commercial clone - 1 tree	Out of 125 grafted cocoa seedlings, 2 trees are from Class I, 146 trees are from Class II, 2 trees from Class III and 1tree is a non- Malaysian commercial cocoa clone.
4	JK, Kg Togis, Ranau	75 grafted cocoa seedlings with clone name BR25 tagging. 75 grafted cocoa seedlings with clone name KKM22 tagging	BR25 (103) KKM22 (47)	Out of 75 grafted cocoa seedlings tagged as clone KKM22, 30 trees were mislabelled and identified as clone BR25. And out of 75 grafted cocoa seedlings tagged as clone BR25, 2 trees were mislabelled and identified as clone KKM22.
5	BB, Kg Tambiau, Ranau	201 grafted cocoa seedlings with clone name MCBC8 tagging.	MCB C8 (138), KKM22 (8) BR 25 (43), KKM 25 (7) MCB C2 (1) Non-Commercial clone– 4 trees	Out of 201 grafted cocoa seedlings, 146 trees are from Class I, 50 trees are from Class II, 1 tree from Class III and 4 trees are unidentified clone (non-Malaysian commercial cocoa clones). 59 trees labelled as MCB C8 were misidentified.
6	MG, Kg Goshen, Kota Marudu	95 grafted cocoa seedlings without No Clone Name Tag.	PBC123 (2), KKM22 (4), MCBC1 (8) BR 25 (61), MCBC11 (1) MCB C2 (16), KKM27 (1), MCBC4 (2)	Out of 95 grafted cocoa seedlings, 14 trees are from Class I, 62 trees are from Class II and 19 from Class III.
7	AG, Kg. Goshen Tagaroh, Kota Marudu	100 grafted cocoa seedlings without No Clone Name Tag.	MCB C1 (3), KKM22 (34), PBC123 (2) BR 25 (42), KKM19 (3) PBC131 (3) Non-Commercial clone– 13 trees	Out of 100 grafted cocoa seedlings, 39 trees are from Class I, 45 trees are from Class II, 3 from Class IV and 13 trees are non-Malaysia commercial cocoa clones.
8	MD, Ranau	100 grafted cocoa seedlings without No Clone Name Tag.	MCB C1 (1), MCBC8 (19), MCBC10(11) PBC123 (5), QH1003 (6), KKM22 (32) BR 25 (8), MCBC9 (1), MCBC11 (6) MCBC2 (9), PBC159 (1), Qh1176 (2)	Out of 100 grafted cocoa seedlings, 74 trees are from Class I, 15 trees are from Class II and 12 from Class III.
9	RB, Keningau	87 grafted cocoa seedlings without No Clone Name Tag.	BR 25 (81) Non-Commercial clone– (6)	Out of 87 grafted cocoa seedlings, 81 trees are from Class II and 6 trees are non-Malaysia commercial cocoa clones.
10	CC, Ranau	40 grafted cocoa seedlings with clone name PBC123 tagging.	PBC123 (3), MCBC1 (1) MCBC9 (1), PBC112 (1) Non-Commercial Clone – (34)	Out of 40 grafted cocoa seedlings, 4 trees are from Class I, 2 trees are from Class II and 34 trees are non-Malaysia commercial cocoa clones.
		39 grafted cocoa seedlings with clone name MCBC1 tagging.	MCBC1 (21), KKM22 (10) BR25 (7) Non-Commercial Clone – (1)	Out of 39 grafted cocoa seedlings, 31 trees are from Class I, 7 trees are from Class II and 1 tree is non-Malaysia commercial cocoa clone
		40 grafted cocoa seedlings with clone name BR25 tagging	BR25 (27) Non-Commercial Clone – (13)	Out of 40 grafted cocoa seedlings, 27 trees are from Class II, and 13 trees are non-Malaysia commercial cocoa clones.
		38 grafted cocoa seedlings with clone name QH1003 tagging	QH1003 (25), MCBC8 (12), KKM22 (1)	Out of 38 grafted cocoa seedlings, all trees are from Class I.
		40 grafted cocoa seedlings with clone name MCBC8 tagging	MCBC8 (40)	All the trees are verified as the correct clone, MCBC8
		40 grafted cocoa seedlings with clone name KKM22 tagging	KKM22 (35), MCBC 1(1) Non-Commercial Clone – (4)	Out of 40 grafted cocoa seedlings, 36 trees are from Class I and 4 trees are non-Malaysia commercial cocoa clones.

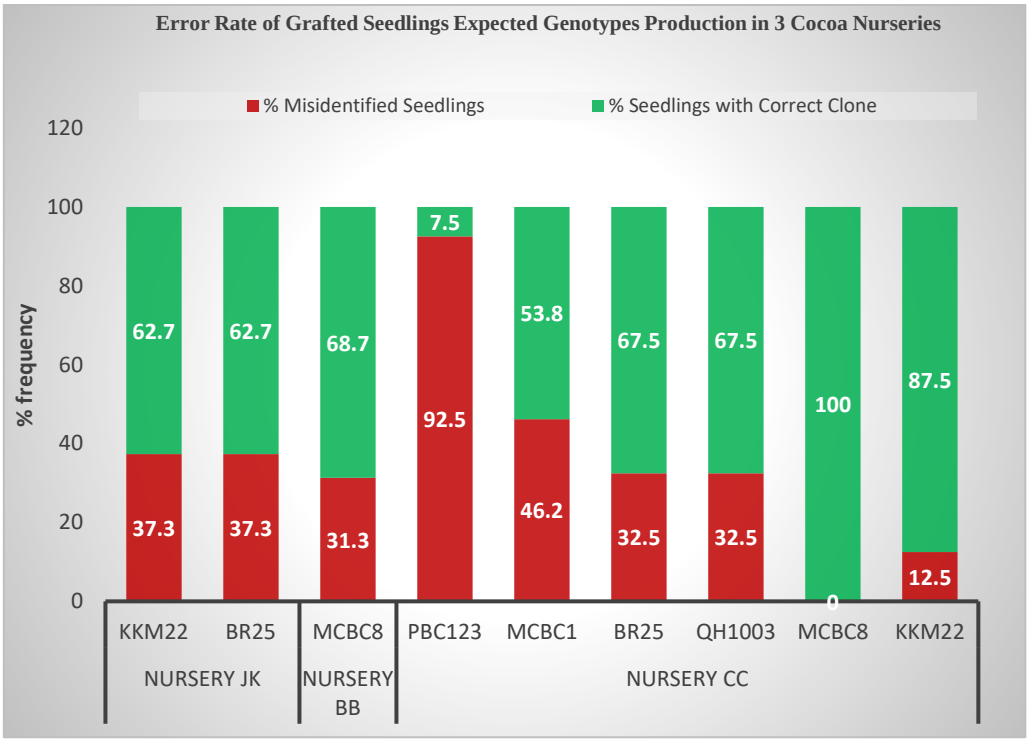

Figure 2: The mislabelling error rates of the grafted cocoa seedlings with clone name tagging at three (3) cocoa nurseries.

Malaysian Cocoa Board, Transfer of Technology and Extension (TOTe) Division (personal communication, 2023), the cocoa nurseries were required to produce / supply grafted cocoa seedlings mostly the Class I of Malaysia cocoa clones.

Table 2 (Identified Clones), it indicated that the grafted cocoa seedlings produced by the cocoa nurseries were more random, with mixtures of a variety of cocoa clones from all classes. This indicates that the actual cocoa clones produced by the cocoa nurseries were based on whichever scions were available for grafting and most probably the clones of the mother plants (scions' sources) were not even verified cocoa clones. It was also detected that out of the 1367 grafted cocoa seedlings analysed, ninety-one (91) seedlings were identified as not from the recommended non-Malaysia cocoa clones, which is 6.7% of all the total sampled seedlings (Table 2).

Although the most favourable cocoa clones for planting are generally from Class 1, Figure 1 showed that almost all the ten cocoa nurseries produced mostly Class 1 and Class 2 cocoa clones with a mixture of cocoa clones in Class 3 and 4. Figure 2 shows the mislabelling error rates of the grafted cocoa seedlings with clone name tagging at three (3) cocoa nurseries. It can be observed that the frequency of misidentification /mislabelling errors was notably high in certain nurseries. This can be observed in CC's nursery, whereby the frequency of misidentification/mislabelling in the case of clone PBC123 was found to be approximately 92.5% while clone MCBC1 was found to be as high as 46.2%. In BB's nursery, approximately 31.3% of the total seedlings showed mislabelling/misidentified, while in JK's nursery, it was around 37.3%. Even in the controlled setting of the CC's nursery, where each seedling was tagged with a clone name, 25% of seedlings were identified as non-commercial or unknown clones, demonstrating that these errors can occur even under presumably more controlled conditions.

The high rate of mislabelling and misidentification observed in some nurseries is a cause for concern. It can lead to significant consequences in cocoa cultivation, such as reduced yield, pest and disease vulnerability, and compromised adaptability to agro-climatic conditions. Mislabelling can occur due to various factors. Frequent multiple introductions, transfers of plants from nurseries to planting in the field, recollection of budwoods for propagation materials and production of grafted seedlings in the nurseries increase the potential of mislabelling errors throughout these processes. Environmental effects and

agronomic inputs can also contribute to the misidentification of scions' source plants by altering their phenotypic traits. The impact of mislabelling errors unfortunately usually unnoticed during the early stage of cocoa planting, nevertheless the distribution and use of mislabelled clones in breeding programmes and mislabelled planting materials in farmers' fields can affect the predicted productivity, expected yield and other desirable traits of the clones (Dadzie *et al*., 2013, Padi *et al*., 2015). This will eventually create a ripple effect of wrong plant materials distribution, when these mislabelled / misidentified cocoa clones are used to repropagate / reproduce more cocoa planting materials for new planting, causing the loss of authentic genetic materials with high quality agronomic traits.

The identification of non-commercial or unknown clones among the sampled seedlings suggests errors in the grafting process and the presence of different genetic backgrounds although these samples dilute the high quality agronomic traits in authentic cocoa clones, on the positive side, they could be potential new cocoa varieties or hybrids that may have desirable traits if further investigation.

The comparison between expected and observed genotypes revealed significant differences, particularly in nurseries where clone name tags were used (Table 2). The mislabelling errors observed in the nurseries indicate a lack of standardized procedures for monitoring and inspecting the accuracy of the scions' sources used in the planting materials propagation. The results of this study also highlight the significance of accurate clone identification in cocoa nurseries for the successful cultivation of cocoa crops. This finding also emphasizes the need for proper training and the establishment of suitable standard operating procedures to ensure the accurate labelling and identity of plants during the propagation process. This also highlights the need for improved labelling practices and stricter quality control measures in cocoa nurseries.

The use of the KokoCorrect™ molecular bio diagnostic kit proved to be an effective tool in identifying and verifying the true identity of grafted cocoa seedlings. The results of this study demonstrate the effectiveness and reliability of the KokoCorrect™ kit in clonal identification of mislabelling errors in grafted cocoa seedlings, overcoming the challenges associated with differentiating cocoa clones based on phenotypic traits alone. The use of specific SNP markers in KokoCorrect™ allowed for accurate and automated screening of large numbers of cocoa planting materials. Moreover, the small set of SNP markers used in KokoCorrect™ reduces costs of analysis, while maintaining high efficiency in identifying and verifying the Malaysian cocoa clones.

CONCLUSION

This research has given valuable insight regarding the mislabelling of cocoa clones at cocoa nurseries located in Sabah. The high rate of inaccurate identification discovered in certain cocoa nurseries presents a course for concern and can cause a ripple effect of further propagation and distribution of inferior planting materials at the farmers' farms, eventually threatening genetic diversity, productivity, disease tolerance, and overall cocoa crop sustainability. Mislabelled clones distributed in the field not only decrease the predicted productivity and yield, but also hamper new cocoa planting programme by diluting high-quality genetic materials with undesirable traits.

Our research has highlighted the urgent need for the implementation of stringent monitoring procedures and quality control measures in cocoa nurseries through the grafting cocoa seedlings production process. Adequate training and the establishment of robust standard operating procedures are also recommended to ensure accurate clone identification and labelling in the cocoa planting materials production.

However, despite these challenges, the presence of non-commercial or unknown clones could also be seen as potential opportunities for the discovery of novel varieties or hybrids, if further investigation/research is done.

The application of KokoCorrect™ molecular bio-diagnostic kit in addressing this issue has been demonstrated successfully in this study. It provides an effective, efficient, and cost-saving solution for accurate clone identification, overcoming the limitations associated with phenotypic trait differentiation. The implementation of this molecular bio diagnostic tool can support the efforts to maintain clonal integrity in the cocoa planting programme, thereby improving overall productivity and sustainability.

Future studies should aim to further validate the use of this kit across different regions and conditions, and work towards the integration of KokoCorrect™ into routine nursery quality control practices. Additionally, an investigation into the root causes of mislabelling in the nurseries could provide insights into

corrective measures to ensure the propagation of correct and high-quality cocoa clones. Further research and implementation of improved practices in cocoa nurseries can contribute to the overall success and sustainability of cocoa cultivation in Malaysia.

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