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Advancing Malaysian sweet potato cultivation through conservation and breeding

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Abstract

Sweet potato (*Ipomoea batatas* (L.) Lam) is a tuber crop from the Convolvulaceae family. It is the one of the most significant food crops globally due to its value and economic benefits crop. Sweet potato is abundant in vitamins and minerals and contains a lot of starch, all of which are essential for food security and health. In Malaysia, sweet potato is classified as one of the staple foods and is commonly used in the food industry to develop downstream products, especially value-added products. Aside from that, sweet potato is a significant food crop in various places in Malaysia, providing the local population's primary income source. Malaysian sweet potato breeding focuses on developing varieties that are high-yielding, disease-resistant, and environmentally friendly such as sustainable water management practices and lower environment impact to ensure the long-term viability of sweet potato cultivation. These efforts are crucial in meeting the growing demand for nutritious and sustainable food sources in the face of climate change and other environmental challenges. This holistic approach to sweet potato breeding not only benefits the local farmers but also contributes to the overall food security and well-being of Malaysia as a whole. This paper reviews the cultivation status and genetically improved sweet potato varieties to increase crop yields and ensure that farmers can continue to produce this valuable food source for years to come. Overall, the findings suggest that Malaysia is on the right track towards securing its food supply through innovative and environmentally friendly practices in sweet potato cultivation.

Keywords: *breeding, cultivation, mechanisation, production, sweet potato*

Introduction

Sweet potato is members of the Convolvulaceae, or family of morning glory. In Malaysia, sweet potato locally known as *keledek*, *ubi stelo* and *ubi jalar*. The chromosomal number for sweet potatoes is $2n = 6x = 90$. This suggests that the plant is a hexaploid, having x = 15 as its fundamental chromosomal number (Swamy 2024). According to Truong et al. (2018), breeding sweet potatoes can be challenging since they are a polyploid crop with high levels of heterozygosity and are primarily an obligatory outcrossing species with a variety of mating incompatibilities. There are 13 species of sweet potato genus *Ipomoea*, (Srisuwan et al. 2006; Mwanga et al. 2017; Byju 2018; Swamy 2024) (*Table 1*). All 13 of these species are native to the Americas except for *Ipomoea littoralis*. In contrast, *grandifolia* and *leucantha* are regarded as hybrids. It is also believed that *grandifolia* is a descendant of *Cordatotriloba batatas* and that *Ipomoea leucantha* is an intermediate hybrid of *cordatotriloba* x *lacunosa*. The *gracilis* is from Australia and belongs to the section *Erpipomoea*, while *peruviana* is from Peru and Ecuador and is currently classified in section *Eriospermum*, series *Setosae*. Only a small number of *Ipomoea* genera are polyploid, and those that have been successfully crossed with other *Ipomoea* species or diploids, according to Norman et al. (2012). According a molecular genetic study, sweet potatoes that are grown are probably autopolyploids, with some restricted recombination evidence (Kriegner et al. 2003; Cervantes et al. 2008). These findings suggest that polyploidy may have played a role in the evolution and diversification of *Ipomoea* species, including sweet potatoes. Further research is needed to fully understand the implications of polyploidy in the genus *Ipomoea*.

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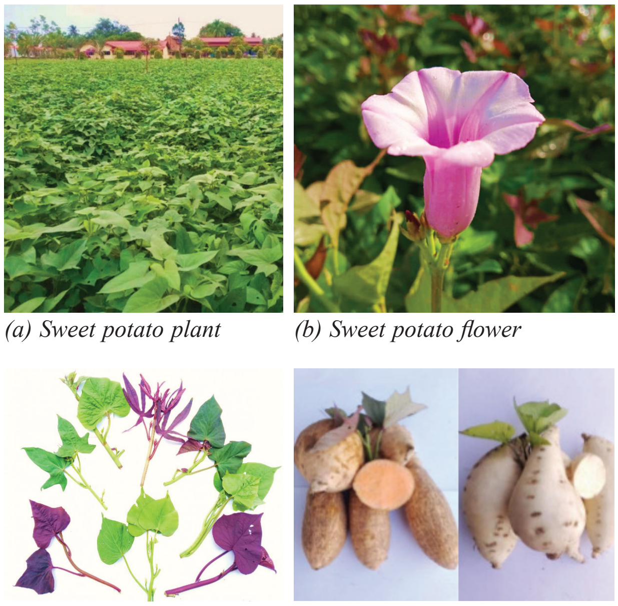
Table 1. Ploidy and compatibility of *Ipomoea* species, section *Eriospermum*, series *Batatas* that are related to the sweet potato

No.	Series of Batatas	Ploidy 2n	Compatibility
1	*I. cordatotriloba 2*	*2x, 4x*	C
2	*I. cynanchifolia*	*2x=30*	C
3	*I. grandifolia*	*2x?*	C3
4	*I. lacunose*	*2x=30*	C
5	*I. x leucantha*	*2x=30*	C3
6	*I. littoralis 2*	*2x=30*	I
7	*I. ramosissima*	*2x=30*	C
8	*I. tabascana 2*	*4x=60*	C
9	*I. tenuissima*	*2x=30*	C
10	*I. tilliacea*	*4x=60*	I
11	*I. trifida*	*2x, 3x, 4x, 6x*	I
12	*I. triloba*	*2x=30*	C
13	*I. umbraticola 2*	*2x=30*	C
14	*I. batatas*	*6x=90*	I

C = self-compatible, I = self-incompatible,



(a) Sweet potato plant *(b) Sweet potato flower*

(c) Sweet potato leaves *(d) Sweet potato tubers*

Figure 1. Morphological of sweet potato (a) plant, (b) flower, and the variations of (c) leaves and (d) tubers cultivated at MARDI Bachok, Kelantan

Sweet potato is distinguished based on botanical morphological traits. It is a creeping herbaceous plant with leaves that are light to moderately green and often have purple colouring running along its tendrils. Their trumpet-shaped corolla, five stamens, superior pistil and capsule-shaped fruit all contribute to the flowers' full blooming. The tuber roots are various in shapes, texture, and variable colours of skin and flesh, such as white, cream, yellow, orange, purple, and deep purple (Aina et al. 2009; Panja et al. 2016; Watson and Dallwitz 2000; Ru et al. 2021; Sawmy 2024). These characteristics are commonly used to differentiate the variety but no longer provide an accurate description of the morphology of the different sweet potato varieties. According to Hue et al. (2010), white and yellow-orange flesh tubers are known as the most common variety (*Figure 1*).

In Malaysia, sweet potato is classified as roots and tubers in the cash crop sector and had been highlighted in the National Agro-Food Policy 2021 – 2030 (NAP 2.0) focusing on food security and economic growth. Cash crops provide the farmers with fairly quick economic returns as early as three months and recorded significant contributions to agrifood commodities at 215.6 mt in 2022 (MOA 2022). Most sweet potato is mainly for fresh consumption and agro-based industries (Rawaida and Nur Fazliana 2019). According to the Department of Statistics (2024), almost 91.6% of sweet potato is utilised as food, followed by 4.8% feed and loss and the rest is for export purposes in 2023.

Nutritional properties

Leaves and tuber roots are consumed in many parts of the world, including Malaysia, as green vegetables (Vimala et al. 2012). These plant organs contain a high content of starch, carbohydrates, lipids, organic acids, pigments, terpenes, phenolics, waxes, volatiles, vitamins, and minerals (Vimala et al. 2012; Nabubuya et al. 2017; Tanaka et al. 2017; Neela and Fanta 2019; Laveriano 2022). Sweet potatoes have 62.20% moisture, 0.89 g of protein, and 0.20 g of fat content. The quantity of energy was 148 Kcal and 35.71 g of carbs. The crude fiber content was 0.70 g, containing 4.99 µg of β-carotene and 17.29 mg of vitamin C (Nicholas 2010, Senthilkumar et al. 2020). According to Antia et al. (2006), sweet potatoes have 24.85% crude protein, 7.20% crude fibre, 11.01% ash, 51.95% carbohydrate, 82.20% moisture, and 351.40 Kcal of energy content. The ash content of sweet potato is approximately 3% of the dry weight, or between 0.3% and 1.0% of the fresh weight basis (fwb) (Truong et al. 2018). Potassium is the greatest mineral in sweet potato, with an average of 396 mg 100/g fwb. Other minerals arephosphorus, calcium, magnesium, iron, copper, and magnesium in insignificant amounts (Woolfe 1992). Vitamins found in sweet potato roots include ascorbic acid, thiamin (B1), riboflavin (B2), niacin (B6), pantothenic acid (B5), folic acid and vitamin E. Vitamins A, C, and E (Tanaka et al. 2017; Neela and Fanta 2019). Tanaka et al. (2017) mentioned that the tuber flesh colour represents the nutrient composition and functional components for good health (Mohanraj and Sivasankar 2014). Allen et al. (2012) reported that the tuber has high levels of dietary fibre with a low glycemic index. Sweet potato also contains dietary fibre, which ranges from 2 to 4% of fresh weight (Mei et al. 2010;

Truong et al. 2012). This made the tuber a good food for diabetic patients. Nevertheless, the nutrient composition varied considerably depending on the cultivar, growing conditions, maturity, and storage. Moreover, sweet potato tuber acceptance among consumers is associated with its eating quality and functional component, particularly the sweet taste for fresh food consumption (Vimala et al. 2012; Wei et al. 2017).

In Malaysia, it involves flour production for beverages and bakery products such as cookies, biscuits, muffins, noodles, breakfast foods, and pies (Tan 2008a, 2008b; Huang et al. 2013; Tan 2015). However, research on the nutritional and chemical profiles, such as the physicochemical properties and their characteristics has been extensively conducted to understand the potential and nutritional information of sweet potato *(Table 2).* Aside from human consumption, it is also used as animal feed and as a raw material in the production of alcohol (Tan et al. 2000; Vimala et al. 2012).

Cultivation and production of sweet potatoes in Malaysia

Sweet potato cultivation and production in Malaysia have been steadily increasing due to the high demand for this versatile crop in both local and international markets. The diverse range of sweet potato varieties available also contributes to its popularity among consumers and farmers alike. Sweet potato is a short-term crop; it's easy to grow and propagate. Generally, sweet potatoes can be grown as an annual plant by vegetative propagation (Swamy 2024). The planting materials can be either storage roots or stem cuttings. Its growth habit is predominantly prostrate with a vine creeping horizontally on the ground. The types of growth habits of sweet potatoes are erect, spreading, and very spreading (Swamy 2024).

Sweet potato cultivation requires soil pH between 5.5 and 6.5 (Tan et al. 2006; Rosnani et al. 2017; Nurul Afza et al. 2021). According to Martini et al. (2018), the site

Table 2. The nutritional properties of sweet potatoes on tuber based on the physicochemical trait

Functional components	Nutritional properties	References
Flesh colour	Flesh colour is contributed by carotenoids (yellow or orange flesh) and anthocyanins (reddish to purple flesh pigmentation) content. Carotenoid content in yellow-fleshed range 1.3 to 3.9 mg 100 g^{-1} dwb Purple-fleshed contains high levels of anthocyanins (peonidin and cyanidin) and total phenolics. For instance, VitAto Anggun and Lembayung have purple-fleshed. The white flesh is Gendut and Telong, while Jalomas has purple skin with a yellowish creamy flesh. Higher total anthocyanin content (348 mg 100 g^{-1} fwb) in boiled and fried tuber (0.223% and 0.216%), compared to raw (0.036%) and baked (0.063%).	Bovell (2007); Tan et al. (2007); Hussein et al. (2014); (Ishiguro et al. (2010); (Lebot et al. 2016); Arnida et al. (2018); Dwiyanti et al. (2018); (Steed and Truong 2008); Truong et al. (2010, 2012); Xu et al. (2015); (Nurul Afza et al. 2018b); (Rosnani et al. 2017); (Nurul Afza et al. 2021); (Tan et al. 2000)
Sweet taste	Sugars (sucrose, glucose and fructose) are the key eating quality component, which varies among the cultivar and climate. Maltose is available in cooked tubers. Among colour flesh, purple-fleshed contain higher reducing sugar content.	Swamy 2024; Kays (2006); Kays et al. (2005); Nabubuya (2012); Lewis et al. 2010); Lončarić et al. (2016).
Starch	VitAto has the highest starch content compared to other local varieties, Anggun 1, Anggun 2, Anggun 3 and Large White	Zulkifli et al. (2021)
Dry matter and moisture content	Moisture content differs and it iscontributed by various factors, including cultivar, location, climate, soil type, pest and disease incidence, and cultivation practices. The average is 30% dry matter content, but it varies by cultivar, climate, soil conditions, and agronomic techniques. Dry matter is contributed by carbohydrates (starch, sugars, pectins, cellulose, and hemicellulose). For instance, the 'Telong' variety dry matter is about 34%. The moisture content in Anggun-2 (72.91%), VitAto (73.58%), Anggun 3 (72.81%), White (67.63%) and Anggun 1 (61.07%).	Ingabire and Vasanthakaalam (2011); Zaharah et al. (2004a); Zulkifli et al. (2021)
pH value and total soluble solid (TSS)	TSS is an important quality criterion that defines the processed food product's quality. The optimal pH ranges from 5.0 to 7.1.	Aina et al. (2009); Kure et al. (2012)
Ascorbic acid and other vitamins	The amount of ascorbic acid decreases with growth stage. Ascorbic acid levels in tubers vary from 9.5 to 25.0 mg 100 g^{-1} fwb and 7.3 to 13.6 mg 100 g^{-1} fwb for dehydroascorbic acid, resulting in a total vitamin C range of 17.3 to 34.5 mg 100 g^{-1} fwb. Other vitamins are thiamin (B1), riboflavin (B2), niacin (B6), pantothenic acid (B5), folic acid, and vitamin E. Mineral composition of potassium (300.02 mg), magnesium (19.09 mg), zinc (0.11 mg), Iron (0.25 mg), manganese (0.22 mg) and sodium (2.60 mg)	Senthilkumar et al. (2020)

where sweet potato grown was mineral soil in Serdang, Selangor. The pH of the colluvium soil was 6.18, the total nitrogen content was 0.11%, the total phosphorus content was 1.87 ppm, and the soil texture was sandy loam. Traynor (2005) suggested that the pH of the soil should be adjusted to about 6.0 by adding lime or dolomite. The pH will be raised by 0.1 unit at 240 kg/ha and 400 kg/ha, respectively. The pH is slightly acidic to neutral pH range is ideal for optimal growth, as it helps in nutrient availability and absorption. If the soil is too acidic or too alkaline, it may affect the plant's ability to absorb essential nutrients, leading to poor growth and yield. Tan et al. (2007) stated that the poorer site on upland mineral soils recorded a significantly lower mean root yield, while one of the Beach Ridges Interspersed with Swales (BRIS) sites produced the significantly highest mean root yield. Therefore, sweet potato cultivation requires well-drained sandy soil with good drainage. The lighter soil structure allows for more efficient and easy harvesting. Furthermore, Usman et al. (2014) discovered that the BRIS soil series, which includes Baging, Rudua, Rhu Tapai, and Jambu, is the best type of soil for sweet potato cultivation. According to Roslan et al. (2011), these three sandy humus Spodosols, Rhu Tapai, Rudua, and Jambu, are rich in spodic horizons with a sandy matrix (> 95% sand), low CEC (0.16 – 4.52 cmol/kg) and high acidity (pH 4 – 5). In Malaysia, roughly 154,000 acres of BRIS soil are currently available, mostly in the east coast states of Peninsular Malaysia, particularly in the Kelantan-Terengganu Plains. According to Zaharah et al. (2004b), sweet potato production in marginal soils necessitates a high fertiliser input and sufficient irrigation. Nonetheless, sweet potato can be produced effectively with good management practices. A yearly soil test is recommended to examine soil characteristics, pH, and nutrient levels before ground preparation. Regular soil testing is crucial for maintaining optimal conditions for sweet potato growth, as nutrient levels can fluctuate over time. Additionally, adjusting the pH of the soil can help improve nutrient availability and overall plant health.

High and low temperature extremes play a key role in sweet potato storage root initiation and bulking at its critical phenophases. An ample day and night temperature is essential for promoting rapid and uniform sweet potato root development and good stand establishment (Gajanayake et al. 2015). Sweet potato can be grown in a warm and hot climate zone, which requires ambient day and night temperatures of 15 to 33°C for optimum growth and root development. Temperature above 25°C is considered optimal for maximum growth (Tan et al. 2010). However, the temperature less than 15°C hinders storage root growth while promoting the fibrous root formation (Wijewardana et al. 2018). Being of tropical origin, sweet potato is more susceptible to low-temperature injury and could not survive the temperature of less than 12 °C (Belehu and Hammes, 2004). The most common symptoms of chilling damages include reduced vine growth and leaf growth, fungal decay, internal tissue breakdown and discoloration, root shriveling, greater weight loss, and failure to sprout (Lukatkin et al. 2012). Sweet potato grows best in an annual rainfall range of 60 to 160 cm^3 (Low et al. 2009). Excess watering at the early stages of the formation may affect growth, resulting in low yield and weed problems (Tan et al. 2010). Malaysia has full sunlight throughout the year with an average temperature of 30 to 32°C, the best factors that are required by sweet potato. Therefore, sweet potato cultivation in Malaysia can benefit from consistent sunlight and optimal temperature conditions. Additionally, monitoring water levels to avoid excess watering during early growth stages is crucial for maximising yield potential.

In general, sweet potato can be harvested at the age of 95 days – 5 months after planting depending on the variety. Determination of the right time to harvest sweet potato is very important because the harvest age affects the chemical composition of fresh tubers and sweet potato flour produced. The age of 120 days is the optimum harvest age for fresh sweet potato based on the highest starch content and minimum fibre. The sweet potato harvest index increased along with the increasing days in the harvest time. Sweet potato harvested at the age of 18 months has the highest harvest index, which has 1.83% differences when compared to sweet potato harvested at the age of 14 weeks. This is presumably because, at the age of 14 – 18 weeks, the tubers are still developing well, thus increasing the productivity of the sweet potato plant. Increasing the age of harvest also increases tuber weight produced by sweet potato plants (Rahmawati et al. 2021). Early-maturing varieties can be harvested as soon as 90 days after planting with good yields. Zhang et al. (2002) state that there are no long-term storage methods for sweet potato due to the warm heat and lack of modern facilities in many tropical places. Nonetheless, the early maturing cultivars produce tubers with a maximum yield within 12 – 16 weeks after planting. For these cultivars, initiation and bulking tuber reach begin at the early maturing stage and decrease or even stop at 12 weeks after planting. Whereas the bulking rate in maturing late-maturing cultivars increases over the middle and later growth periods. The maturity level of sweet potato is divided into three maturity index groups. Maturity index 1 denotes an immature feature, such as a smooth skin surface with hair roots that are less dense, easily broken, and rubbery when cut. Mature index 2 has a rough skin surface, no hair roots, and tubers that are dense and difficult to break, but maturity index 3 is more mature. There are cracks in the skin, and it is rough. When cut, the flesh is elastomeric rather than dense and hollow and emits a thick rubbery substance (FAMA 2008). Tan (2015) reports that sweet potato can be harvested 14 to 16 weeks after planting in the tropics. In the temperate zone during the summer, certain sweet potato cultivars are harvested in the 16^{th} week after planting, or after the 20^{th} week. This crop might well be grown in the tropics but also in the tropics and the temperate zone during the summer months (Rosnani et al. 2017; Nurul Afza et al. 2021). Sweet potatoes have a relatively short crop cycle, making them suitable for cultivation in both tropical and temperate regions. This flexibility allows for harvesting within 14 – 20 weeks after planting, depending on the specific climate conditions.

Mechanisation of sweet potato production

Sweet potato is planted in mounds or raised beds. This provides the developing roots with loose, friable soil that allows them to fully develop potential size and shape. It also facilitates harvesting with a mechanised digger and allows for appropriate drainage (Traynor 2005). In the agricultural industry, mechanisation has proven to be a viable solution to obstacles such as labor shortages and low production. The implementation of a mechanised system helps to reduce production costs, increase quality, and eliminate tiresome labour tasks. Due to the reason, MARDI has developed a comprehensive sweet potato machinery package, from land preparation to harvesting (Anuar et al. 2019). They also stated that the performance evaluation of the disc ridger for the formation of raised beds as well as other operations such as cultivation and fertiliser application revealed that the working rates were 0.27 ha/h and 0.25 ha/h, respectively. Thus, MARDI has recommended a single-row planting system with high bed planting for sweet potato cultivation, and the utilisation of disc ridges is critical, particularly during bed formation, inter-row planting, and fertiliser application activities (Anuar et al. 2021). The 3-in-1-disc ridger was used for three major operations in sweet potato production which were making a raised plant bed, fertilising and mechanical weeding. A raised planting bed was made using this machine during land preparation. Meanwhile, after three weeks of planting, the machine was used again for the 1^{st} fertilisation and mechanical weeding. Then, the next fertilisation process was performed on the 6^{th} and 9^{th} weeks of planting. This recommendation is based on the efficiency and effectiveness of the disc ridger in various stages of sweet potato cultivation. By following MARDI's recommendation, farmers can optimise their land preparation and planting processes to improve yields and productivity. Additionally, the use of a single-row planting system with high bed planting has been found to improve soil aeration and drainage, leading to healthier sweet potato crops. Farmers who adopt these recommendations may also benefit from reduced labor costs and increased efficiency in managing their sweet potato fields.

Yield potential of sweet potatoes in Malaysia

Sweet potato tuber weight is one of the important yield components. The tuber yield is determined by the growing season, tuber growth, and tuber per plant number and weight, or the difference in bulking rate, which differs between cultivars. In some circumstances, the genotypic and environmental conditions may have a direct physiological effect on the yield. For optimal yield, it is essential to choose cultivars that are well-suited to the specific climate and growing conditions. Additionally, proper soil preparation and nutrient management are crucial factors in maximising sweet potato tuber weight and overall yield. China, Japan, and India have achieved an average fresh tuber production of 10 – 25 t/ha in 16 to 20 weeks after planting. These countries have advanced technology of favourable environmental conditions that support optimal sweet potato growth (Ravi and Saravanan 2012). The yield performance of sweet potato cultivation in Malaysia was previously studied, and the fresh root yield for the majority of the varieties evaluated was quite poor. Zaharah et al. (2004a) found that a traditional variety of *Susu Lembu* produced the highest average total fresh root yield (18.2 t/ha) and Tan et al. (2007) stated that a traditional variety of *Merah Manis* recorded the highest total fresh root yield (26.2 t/ha) in different agro-ecologies. Recently, VitAto, the orange-fleshed sweet potato, recorded an optimum yield of 33 t/ha (Nurul Afza et al. 2018b). Martini et al. (2018) have found that Accession 6 among purple-fleshed sweet potato recorded the highest tuber yield, with 34.6 t/ha. Nurul Afza et al. (2018c) revealed that the mutant purple-fleshed sweet potato genotypes V6D3-16 and V6D3-18 significantly have the highest average number of marketable roots, with 56.75 and 54.25, respectively. The genotype V6D3-18 had the highest root yield at 32.62 t/ha and was followed by V6D3-16 with a yield of 31.62 t/ha. Furthermore, the Lembayung purple-fleshed sweet potato has a yield of 33 t/ha (Nurul Afza et al. 2021). This suggests that the sweet potato crop in Malaysia is increasing in yield. Sweet potato yields are predicted to reach 30 t/ha. With a crop density of approximately 33,333 plants/ha, the minimum weight per plant is projected to be 1.00 kg. As a result, sweet potato production, which requires minimal input and is a short-term crop, is shown to be very cost-effective and viable. Additionally, the increasing yield of sweet potatoes in Malaysia may be attributed to advancements in agricultural practices and technology. This positive trend in sweet potato production could have significant implications for food security and economic growth in the region.

Productivity of sweet potato in Malaysia

In terms of cultivation, Loebenstein and Thottappily (2009) mentioned that sweet potato is cultivated twice a year, depending on the region and planting season, and require minimal input. Tuber yield varies widely among sweet potato cultivars and individual plants of the same cultivar due to propagation material and soil conditions (Ravi and Saravanan 2012). Economically, sweet potato is a valuable crop and are listed as the seventh most important food crop in the world after rice, maize, wheat, soybeans, potatoes, and cassava by FAO. Based on FAO reports in 2019, China is a major producer of sweet potatoes nowadays, which is 64.4% of the total world production (FAO 2019).

Sweet potato is grown for small-scale production in Malaysia. Fresh sweet potato is harvested and sold at the local market. It is readily accessible for immediate consumption, and some are even used in the traditional cake-making industry (Rawaida and Nur Fazliana 2019). According to Tan (2008b), sweet potato roots and leaves can be eaten as vegetables in regular meals. The harvested vines are not thrown away; instead, they are used as cattle feed. Due to the limited and discontinuous supplies, market values fluctuate. This demonstrates that sweet potato shoots were consumed as a vegetable by the local community. Thiyagu et al. (2013) suggested MIB05 be suitable for use as vegetable shoots. The organoleptic evaluation showed that this genotype produced the highest shoot tip yield and also a high number of shoot tips. The genotypes generally have light green coloured leaves and are less fibrous, which becomes one of the main criteria for selection for vegetable use. They also reported that genotypes MIB13 and MIB20 are potential varieties having high average shoot tips and root yield production for germplasm evaluation at Serdang, Malaysia. Data on crops and production areas in Malaysia, categorized by state and agroecological zone (AEZ). Perak, Kelantan, Selangor, and Johor are among Malaysia's major sweet potato-producing states, as previously stated. Even though there is a wide range of planted areas across the country, crop priority in terms of area and output differs from one state to another, depending on the crop's compatibility with local conditions. Sweet potato cultivation is found to be suitable in Kelantan, Selangor, and Johor, but it is moderately acceptable in other states such as Perak. In Perak, colluvium-type mineral soils and sand tailings cover the majority of the sweet potato cultivated area (FAO 2004). However, when planting sweet potato in marginal soil conditions, more input is required to make the soils suitable for sweet potato growth and development (Usman et al. 2014). According to the Department of Agriculture (2022), Perak is the leading producer of sweet potato shoots (45.33 mt) and also a major producer of sweet potato in Malaysia. The total production was 27,422.40 mt with a planted area of 1,480.71 ha and a production value of RM60,329.28 million. This is followed by the states of Kelantan, Johor, and Selangor, with a total cultivated area of 573.24 ha, 206.10 ha, and 156.50 ha, respectively. The total value of production for Peninsular Malaysia was RM95,237.68, and the cumulative production value was RM98,283.23, including Sabah (*Table 3*) (DOA 2022).

Overall, sweet potato production in Malaysia has shown an increasing trend from 2017 until 2022 as depicted in *Figure 2*. The production continuously increased from 2017 until 2020, which showed a slight decrease and later continued to spark its production. However, in 2022, the production decreased 19.9% due to climate change. In terms of productivity, sweet potatoes continuously increasing over the years. This shows, that sweet potato can produce more although the planted area shows a decreasing trend. This is due to demand in the market for fresh roots. It is envisioned that sweet potato's potential as a raw material in agro-based, especially food-based, industries hold the key to expanding markets and, therefore, production as well.

Figure 2. Planted area (ha), production (mt) and productivity (mt/ha) of sweet potato (2017 – 2022)
Source: MOA (2022)

Table 3. Productions of sweet potato by state, Malaysia in 2022

State	Planted area (ha)	Harvested area (ha)	Production (mt)	Value of production (RM'000)
Johor	244.40	206.10	2,398.00	5,275.61
Kedah	2.66	2.64	43.34	93.14
Kelantan	576.55	573.24	9,257.64	20,360.20
Melaka	16.85	15.95	129.91	258.40
Negeri Sembilan	4.20	4.20	76.83	169.02
Pahang	60.89	59.34	852.97	1,876.53
Perak	1,480.71	1,415.06	27,422.40	60,329.28
Perlis	2.72	2.72	30.00	66.0
Pulai Pinang	1.19	1.19	23.65	52.03
Selangor	156.90	156.50	2,479.64	5,455.21
Terengganu	72.20	67.50	591.64	1,302.26
Peninsular Malaysia	2,619.27	2,504.44	43,302.31	95,237.68
Sabah	42.80	34.20	267.90	589.38
Sarawak	114.21	104.85	1,116.44	2,456.17
Total	2,776.28	2,643.49	44,686.65	98,283.23

Source: Department of Agriculture Malaysia 2022

Germplasm collection and conservation

According to Roullier et al. (2013), sweet potatoes were introduced to Malaysia by the British through trading activities. The establishment of a germplasm collection is essential for an effective crop improvement program. In addition, conservation is needed to keep the accession collections from becoming critically endangered. To develop improved crop varieties, plant breeders require genetically diverse materials. The greater the variability of the gene pool, the greater the probability that desirable genes will be found. In the previous report by Saad (1999), from 1983 to 1996, a total of 151 sweet potato accessions were collected and maintained at the Plant Genetic Resources Centre (PGRC), Universiti Pertanian Malaysia (UPM) (currently known as Universiti Putra Malaysia) comprising 99 accessions from Sabah and Sarawak and the rest from Peninsular Malaysia. In the following years, there was an increase in the number of collections that were obtained from the Asian Vegetable Research and Development Centre, Taiwan (AVRDC), International Potato Centre, Peru (CIP), National Agricultural Research Centre, Tsukuba, Japan (NARC) (Zaharah et al. 2004a), Irian Jaya and Java, Indonesia and Visayas State College of Agriculture, Philippines (ViSCA) (Saad 1999). Sweet potato germplasm in the form of true seeds (poly cross seeds), meristem tissues (clonal introductions) or seed tubers. In 1999, the total number of sweet potato germplasm maintained was 217 accessions. However, the number is much smaller than total number of germplasms collected or received. It is due to pest and disease attacks, especially viruses and mycoplasma, and some of them were identified as duplicates and were discarded.

To date, the sweet potato germplasm collection and conversation have been carried out at the Malaysian Agricultural Research and Development Institute (MARDI) at Bachok, Kelantan. It has been reported, that there are just 63 sweet potato germplasm accessions, which include both local and released varieties. In addition, some collections were obtained through international networking programs such as IPGRI, CIP, and AVRDC. From the accessions collected and conserved, the biological status consisted of 29 traditional varieties, seven breeding lines, six released varieties, and 21 improved cultivars. According to the numbers of locations/ sources, approximately 40 accessions from local, six accessions from Indonesia, five accessions from China, three from Korea, and the rest are unknown locations. Besides, the morphological characterisations for all accessions have been through the evaluation and selection scheme of yield trials for systematic testing. The data help in the subsequent identification of the clones and prevent mix-ups. However, there are various issues and constraints contributing to the rapid decline in this species' population (Nurul Afza et al. 2024). It's because of a lack of funds, priority materials, and field GenBank standards and management. Aside from that, there is a lack of information and germplasm exchange, a lack of public awareness, a lack of database management such as coordination, standards of procedure (SOP), and geographical gaps (Nurul Afza et al. 2018a). As a consequence, action must be taken to prevent the loss of sweet potato germplasm. From this vantage point, it's preferable to characterise sweet potatoes and enhance their usage in breeding activities.

Breeding programs

Sweet potato breeding targeted at increasing production at least 30 t/ha, includes morphological and physiological characteristics, physicochemical attributes, and functional properties. Furthermore, sweet potato genetic improvement aims to improve eating quality, pest and disease resistance, adaptability in different ecological agroecological conditions, and climate change resilience. Recognizing sweet potato' great potential in combatting malnutrition and food security has led to increased research efforts in recent decades to improve their cultivation and processing (Laurie et al. 2013), primarily for high-quality cooking sweet potato production.

In Malaysia, MARDI is the country's primary custodian of crop genetic resources, with worldwide and national crop mandates. It has global responsibility for the conservation of bananas, sweet potato, and citrus, and national responsibility for crops such as rice, tropical fruits, and some herbs, as well as medicinal plant species (Mohd Syukor et al. 2015). MARDI is also conducting crop plant breeding activities, including root and tuber crops such as sweet potato, cassava, and yams. The sweet potato breeding program that aims to produce non-sweet and super-sweet sweet potato is one of the tasks under MARDI. To date, few varieties have been introduced for food processing and direct consumption. Breeding activities are carried out by research institutions, public and private universities, extension agencies, and private companies. The cooperation between these organisations is very encouraging in terms of improving crop genetics. It has been reported that a total of 97 imported varieties as an introduced PGRFA from the International Potato Centre (CIP) and International Centre for Tropical Agriculture (CIAT) were used alone with local germplasm to improve sweet potato breeding (Nijar 2012). The ultimate goal of the breeding of sweet potato is to improve smallholder incomes and transform this crop into a raw material for agro-based industries (Tan 2008b). Throughout the 7th and 8th Malaysian Plans, the breeding program targeted the development of sweet potato varieties for fresh consumption (Tan 2000), high starch and animal feed (Tan et al. 2000), and processing technology into food product development (Tan et al. 2007). Starting in the 9th Malaysian plan (2005 onwards), breeders focused on varieties with yielding high-yielding and highly nutritious characteristics, such as high content of β-carotene (Tan 2015).

In the previous research reported by Tan (2008a), most of the sources of seeds were obtained from controlled hand crosses, poly crosses, or imported from the CIP GenBank and also from other foreign sources. The seeds were planted in individual small polybags. Subsequently, seedlings and clones were evaluated and selected through single rows based on their performance, such as marketable root number and yield, total root yield, and harvest index. In addition, morphological traits such as root shape and growth habit were also identified as important traits that influenced the yield. Additionally, the observation and screening for pests and diseases were also carried out at an early growth stage (Tan 2008a). The potential or superior lines were then selected and shortlisted, and those lines were tested in multi-location trials (MLTs) in different agroecological conditions. The MLTs aim to evaluate yield and yield components via the interaction of genetics and the environment. The elite breeding lines with desirable traits were then identified by the selection of two or three clones. In the following season, the selected clones were then carried out in the local verification trials (LVTs) at farmers' fields. Finally, the superior clones with good agronomic traits as well as high yield potential, high quality of nutrition and physicochemical attributes, and at least moderate resistance to major pests and diseases were released as a new variety (Tan 2008a). This is a conventional breeding method accomplished by natural selection.

MARDI is attempting to improve variety development as well as the production and quality of purple sweet potato through mutation breeding (Nurul Afza et al. 2018c). In this research, an attempt was made to find out the effects of gamma rays on the survival of sweet potato vine cuttings of potential genotypes to identify the lethal dosage (Thiyagu and Sobri 2018). Once the material has been irradiated with gamma rays, the evaluation of clones may enter the normal scheme of selection. The mutant purple sweet potato varieties can enhance the production yield with low input and also cater to the needs of farmers, industrial processes, and end consumers, either for fresh consumption or products. The varieties developed have high nutritional values of antioxidants and anthocyanins, which are excellent for human health (Nurul Afza et al. 2018c).

Sweet potato traditional varieties

The sweet potato varieties planted in Malaysia vary among the states. Farmers are interested in planting sweet potatoes that have wide adaptability to a range of soil types in Peninsular Malaysia (Tan 2000). In addition, farmers' selections are based mainly on the fresh yield and marketability of the roots produced (Zaharah et al. 2004a). The popular varieties are *Ubi Biru*, mostly planted in Johor; Kuala Bikam 1 and Kuala Bikam 2, - (also known as the Cameron variety), *Susu Lembu*, and Miang, planted in Perak. Variety *Ubi Jepun* was popular in Kelantan and Terengganu, and *Gurun Puteh Lama* was planted in Kedah, and Melaka. Variety Bukit Naga was mostly planted in Selangor (Tan 2008a). Most of these varieties were commercially planted in the 1990s, giving mean fresh root yields of about 20 to 25 t/ha on both mineral and drained soils (Tan 2000). Other than that, there are other local varieties planted in Malaysia, such as *Batu Kelantan*, *Biru Putih*, *Oren* and *Indon* (Hue et al. 2010).

Varietal release

MARDI released *Gendut* in 1994. The variety first appeared in 1989 as a group of accessions from North Carolina State University, USA, distributed as tissue cultures. *Gendut* yielded 20 – 25 t/ha and was well adapted to peat soils and mineral soils. According to Tan (2000), *Gendut* also adapted to sandy soil type including BRIS and tin-tailing, as well as acid sulfate soils. *Gendut* is especially well suited as an Irish potato replacement when creating fries and other meal preparations. *Gendut* has a spherical, elliptical shape and a yellowish-to-brown skin tone. In addition, UPM produced and distributed UPMSS5, a new national variety (Saad 1999; Zaharah et al. 2004b). The variety UPMSS5 recorded a potential marketable fresh root yield of about 5.9 t/ha with a total fresh root yield of 8.8 t/ha. The dry matter content was 24%. This variety was also adaptable to various soil types (Zaharah et al. 2004b).

In 2000, *Telong* and *Jalomas* were also released by MARDI in Kg. Telong, Bachok, Kelantan. Telong was an F1 seedling clone developed from a poly-cross (CN 1826-76) using the Korean accession I1167 as the maternal parent. Telong has elliptic-shaped roots with light brown skin and light-yellow flesh, while its shoots are green with a purple edge. In 1993, *Jalomas* was first made available in a batch of true seeds from CIP, Peru. It is descended from the cross of JPKY 10-010 and PC90. The flesh is orange with golden stripes, while the roots are ovoid and reddish-purple. Both the Telong and Jalomas cultivars yield between 25 and 30 t/ha and are highly adaptable to a variety of agroecologies. It is also significantly higher in dry matter content (> 30%) and is suitable for processing into flour, from which a range of food products can be made (Tan et al. 2000).

After a 10 year breeding project that tested numerous high β-carotene lines against control varieties over several seasons in different ecologies and agroecologies, VitAto was made available. On June 12th of 2007, in MARDI Bachok, Kelantan, VitAto was introduced by the then Minister of Agriculture and Agro-Based Industries, Hon. Tan Sri Dato' Seri Hj Muhyiddin B. Yassin. The cultivation of the VitAto outperforms currently grown orange-fleshed varieties in Malaysia in terms of yield performance, even on marginal soils like tin tailings, BRIS soil, and acid sulfate soils with appropriate agronomic amendments (Nurul Afza et al. 2018b). It is particularly well suited to BRIS soils, where after four months of planting, root yields of 32 – 35 t/ha are attained. It is proven that the VitAto is a suitable variety for cultivation in Kelantan and Terengganu because the VitAto variety was reported to grow well on BRIS soil (Zaharah and Tan 2006). VitAto is rich in beta carotene (2066 mg 100/g), high in vitamin C (1.33 mg 100/g), high in dietary fibre content (2.49 mg 100/g), and has a low glycemic index of 54. VitAto exhibited the highest starch content among all the varieties, revealing its suitability for the starch extraction process. Among the three parts of VitAto, the highest starch content was recorded by its cambium and parenchyma part (17.17%), followed by the cortex (17.02%) and the skin (16.95%) (Zulkifli et al. 2021). The starch content of VitAto can be used for many food applications, including the production of cakes, muffins, cookies, noodles, extruded snacks and also chiffons (Mohd Hanim et al. 2014). Besides, the starch can also be used as a thickener, water binder, emulsion stabiliser and gelling agent (Sanoussi et al. 2016). These good nutritional qualities of VitAto make it a very good supplement food for Malaysians (Mahmood et al. 2007). Normally, for small-scale production, local communities use VitAto as an ingredient in traditional foods such as *kuih muih* and *kerepek* or crips. MARDI has also produced technology for food processing and products based on VitAto. VitAto is very suitable for being processed into flour and is more nutritious than wheat flour. In addition, VitAto is also suitable for frozen food products such as fries, cakes, buns, and muffins, as well as juice and cordial (Nurul Afza et al. 2018b).

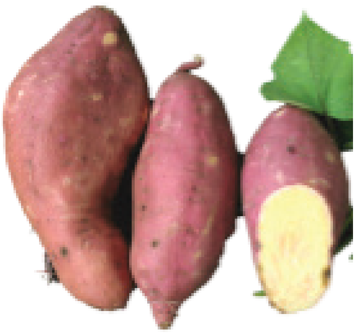
Anggun is a purple-fleshed sweet potato variety. The research was started in the 10th Malaysian Plan from 2011 to 2015, which focused on the production of nutritious sweet potatoes that are safe to eat. Starting from the collection of genetic resources of purple-fleshed sweet potatoes throughout Malaysia, it was then propagated, screened, and selected under different agroecological conditions. Three clones of purple-fleshed sweet potato was selected based on the yield potential and antioxidant content of anthocyanin. MARDI introduced three clones of purple-fleshed sweet potato, namely Anggun 1, Anggun 2, and Anggun 3, on September 24th, 2017, at MARDI Bachok, Kelantan. The average yield of Anggun production is between 20 and 30 t/ha, and the total anthocyanin content is 185 – 316 mg/L (Rosnani et al. 2017). Shaari et al. (2020) observed the phytochemical availability (total phenolic content), total flavonoid content, and anthocyanin content of *Anggun* in three different parts of the tuber: the unpeeled tuber, the peeled tuber, and the skin of the tuber. The Folin-Ciocalteau (FC) assay showed that phenolic content for unpeeled tuber was 41.14 ± 1.69 mg GAE 100/g dwb, and for peeled tuber was 42.24 ± 2.19 mg GAE 100/g dwb, which was significantly (50%) higher than the skin of the tuber with 26.01 ± 2.04 mg GAE 100/g dwb. In terms of flavonoid content, the highest value was retained in the peeled tuber (9.55 ± 0.82 mg quercetin 100/g dwb). The peeled tuber of Anggun had the highest total anthocyanin content (9.43 ± 0.08 mg 100/g dwb). In addition, Zulkifli et al. (2021) determined the proximate composition and energy value of five common varieties of local sweet potatoes, including *Anggun*. The findings indicated that *Anggun* 2 has the highest moisture content of 76.87% moisture, higher than *Anggun* 3 (72.81%) and *Anggun* 1 (61.07%). *Anggun* 3 (0.61%) has the highest protein content, followed by *Anggun* 1 (0.43%) and *Anggun* 2 (0.32%).

Recently, MARDI has attempted to develop purple sweet potato varieties by inducing gamma-ray radiation. This research intends to boost production yield and crop area, as well as economic improvement, by implementing innovative strategies for promoting healthy food and encouraging sustainability (Nurul Afza et al. 2021). The vine cuttings of genotype *Anggun* 3 were subjected to different levels of gamma radiation (20–150 Gy) using Cs-137 as the radiation source. Based on the survival reduction rate of the treated genotype, the LD50 dose for gamma rays was proposed to be applied to sweet potato radiation to achieve a genetic improvement (Thiyagu and Sobri 2018). In March 2021, MARDI released a new mutant purple sweet potato, namely *Lembayung*. *Lembayung* is a high yielding potential variety with an average yield of 25 – 30 t/ha, as well as a nutritious variety with a high anthocyanin content (7.05 mg 100/g dwb). It's great for serving as fresh consumption and may also be used for flour processing. It has been discovered that this mutant purple-fleshed sweet potato can provide a great opportunity for the industry to increase farmer income and food product entrepreneurs and also stimulate the sweet potato industries in Malaysia to meet the increasing local demand. It offers a host of awesome benefits as a healthy food colouring agent and also helps regulate blood pressure, and aid athletic performance, and making it a versatile and valuable addition to any diet (Noor Ismawaty et al. 2020).

(a) Bukit Naga

(b) Gendut

(c) Telong



(d) Jalomas

(e) VitAto

(f) Anggun 1

(g) Anggun 2

(h) Anggun 3

(i) Lembayung

Figure 3. A few popular sweet potato varieties cultivated in Malaysia

Conclusion and perspectives

Even though sweet potato is a cash crop grown on a small scale in Malaysia, it has significant commercialisation potential due to its economic viability, as well as its excellent nutritional content for use as a health food. However, a lot of challenges, such as improved genetics and increased productivity, will need to be addressed in the future. Future trends are tough to predict. Nonetheless, through the numerous efforts created by the government in agricultural research and development programs, it is feasible to affect production trends by addressing three sorts of issues; supply, marketing, and demand. The key difficulties are a lack of costs and finance, uncertain production and demand, availability of planting areas, climate change, the development of high-value-added products, and the need to meet new demand. Furthermore, the genetic improvement of sweet potato is limited by a lack of seed resources. Aside from that, mechanisation in sweet potato agriculture is still lacking. Disease and pest resistance, as well as storage capacity, must be increased to maintain long-term productivity and supply. To ensure that development and manufacturing have a high impact and are competitive, all of these elements must be considered. Consumers are also concerned about the health benefits of sweet potato, as well as the great quality of future sweet potato production. It is critical to improve eating quality and levels of elements related to health function, such as anthocyanins, β-carotenes and dietary fibers, to promote consumer health functionality and increase consumption. To address these increased demands, new cultivars carrying specific colours or starches with novel qualities must be developed.

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