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FACT SHEET

THE POTENTIAL FOR MIRACLE FRUIT PRODUCTION IN HAITI

Agronomic Performance and Economic Peformance of Synespalum dulcificum in Haiti

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Generalities

Synsepalum dulcificum commonly called miracle fruit or miracle berry, is a perennial, evergreen shrub originating from the hot, humid lowlands of West Africa. It grows best in partial shade and in well drained soils with a low pH. Although it can reach up to 6 m tall in its native habitat, it is usually no more than 1.5 m in pots (Figure 1) (Oumorou et al., 2010; CRFG, 1996; Bartoshuk et al., 1974; Brouwer et al., 1968).

Botany

Taxonomy

The plant belongs to the Sapotaceae family which is composed of around 40 genera. The genus *Synsepalum* is restricted to the tropical regions of Africa and comprises around 30 species. The *Synsepalum dulcificum species* is one of the eight most useful species for West African communities and the most widely distributed species within this genus (Akoègninou et al., 2006; Burkill, 2000).

Figure 1. A full-grown miracle fruit in a natural environment and one grown in a 20-gallon pot. (Photo credits: Ayensu 1972 and Maria Brym 2019)

Leaves

The miracle fruit bush has relatively small leaves pointed at the apex. The leaves are entire, symmetrical and obovate–lanceolate to broadly lanceolate. They measure in general 4-7.5 cm long over 3-4 cm wide for a length/width ratio of 2:1. A small petiole attached them to the branch around which they are distributed in small clusters (Figure 2) (Ayensu, 1972; Lim, 2013).

Inflorescence

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The flowers are white, small and can be in solitary or in small clusters. Miracle fruit flowers are composed by 4 to 5 sepals and 4 to 5 petals. The reproductive parts are composed of 5 stamens and a single ovary with a simple style and an inconspicuous stigma. They are hermaphroditic and autogamous (Ayensu, 1972; Lim, 2013). Although cross pollination is possible, a more in-depth understandings of the pollination mechanisms is still needed to confirm the hypothesis (Figure 3).

Figure 2. Leaves shape from two different types of Synsepalum dulcificum. (Photo credit: Maria Brym, 2019)

Figure 3. Inflorescence and fruit of the miracle berry. From left to right: flower cluster of miracle fruit; matured fruits in the bush; harvested miracle fruit and peeled miracle fruit. (Photo credit: Demesyeux, L. & Brym M., 2019)

Fruits

Multiple times a year, the plant flowers and produces a small ellipsoid berry of approximately 2 cm long and 1 cm wide that turns from green to red at maturity. Some types reportedly bear yellow fruits (Ayensu, 1972; Lim, 2013). The fruit contains a seed that is surrounded by a thin layer of white pulp that has a mild cherry-like taste. This pulp contains a non-caloric, natural sweetener glycoprotein, called miraculin and this is the primary purpose for miracle fruit cultivation (Figure 3) (Inglett and Chen, 2011).

Utilization

In its center of origin, the plant has been exploited by the indigenous people for centuries in their diet as well as for its medicinal properties (Burkill, 2000). The leaves, bark and roots are used in the treatment of diabetes, enuresis, kidney diseases and other afflictions. The fruit is a rich source of vitamin C, leucine, flavonols and anthocyanin (Du et al., 2014).

The fruits also render sour foods and drinks more palatable changing a sour taste into sweet taste (Burkill, 2000). The sensory impact is more similar to sugar than other natural, non-caloric sweeteners. This change in taste is triggered by a glycoprotein called miraculin, which is not sweet itself (Brouwer et al., 1968). The production of miraculin in the fruit starts at the color break, around 6 weeks after pollination (Sun et al., 2007). The native state of miraculin is a dimer (40-48 kD) while its denatured state a monomer. The taste-modifying activity of the protein occurs at an acidic pH, with a maximum activity at pH 3.0 and lowest at neutral pH. The monomeric form of miraculin itself has no activity at all pHs, and the dimerization of the monomeric form is required in order to trigger the taste altering property of the miraculin (Ito et al., 2007).

The sweetening impact of miraculin can last more than 1 hour after being held in the mouth for approximately 3 minutes. It can trigger sweetness from a large range of acids such as HCl, lactic acid, formic acid, oxalic acid, acetic acid and citric acid (Kurihara and Beidler, 1969).

Taste-Altering Mechanism

The mechanism of the taste altering property of the miraculin has been studied by several investigators. According to Kurihara and Beidler (1969) sweetness is induced when the miraculin molecule binds to the taste receptors and activates the sweet receptors at low pH. Koizumi et al. (2011) confirmed that miraculin activates hT1R2-hT1R3 which is the human sweet taste receptor at low pH, suggesting the same mechanism previously described by Kurihara and Beidler in 1969.

Propagation

Miracle fruit can be propagated by seeds as well as by vegetative means, including micropropagation. Although propagation through cuttings is the fastest way to reach the reproduction phase, it has been observed that it is the most challenging way to reproduce miracle fruit due to the complications encountered when it comes to stimulate healthy roots from the cutting (Joyner, 2006). In parallel, Chen (2012) and Ogunsola an Ilori (2008) have found some success reproducing miracle fruit through micropropagation method by using indole butyric acid in the first study and a specialized medium (Murashing-Skoog) with a combination of chemicals for the second one to stimulate shoot proliferation and the rooting process. Thus, reproduction by seed seems to be the best reproduction technique for this crop since it offers faster growth and preserve their genetic variation (Achigan-Dako, et al., 2015).

When it comes to seed propagation, post-harvest length prior planting, seed coat, and incubation temperature play an important role in seed germination although more studies on these factors would bring more certainty on our current knowledge. Nevertheless, in a study conducted in 2018 by Chambers, et al., a maximum of 63% of the seeds without seed coats, at 0 drying days and incubated at 30°C germinated after the 10 days that lasted the experiment, while only 20% of those seeds germinated when they increased the drying days to 2 days after harvest. Of all these factors, the seed coat seems to be the most significant factor considering that only a few seeds with their intact seed coat germinated at 30°C during the 10 days of incubation period. The same study demonstrated that miracle fruit seeds can germinate and produce decent roots and shoot at 23°C too, but the root growth is inhibited at 37°C (Chambers, et al., 2018).

Moreover, seed moisture and storage temperature play an important role as they affect the viability of the seeds. For example, a study showed that the viability of seeds is nearly 100% when they are fresh with 36.6% of water content. However, when the seeds lose their water content to 20% due to a prolonged utilization after

harvest, a total loss of viability was recorded. The same detrimental result was found when the seeds where stored at 0°C while storage at 25°C help maintain the seeds shelf life for 28 days but with a very low germination rate (Tchokponhoué et al., 2019).

Another important factor to consider when it comes to sexual reproduction of miracle fruit is surface sterilization of the seeds as they are prone to microbial contamination. As a first step to germinate miracle fruit seeds, it is important to clean the pulp out of the seeds prior removing the seed coats to facilitate better and faster germination. Chambers, et al., evaluated in 2018 the effects of various surface sterilization treatments on miracle fruit seeds germination including water control, 10% bleach, 3% H_2O_2, and 2% NaDCC. The germination rate was higher for the sterilization with water (53%) followed by 47% for the 10% bleach and 43% for the 3% H_2O_2, although the microbial growth was only 3% for the 3% H_2O_2 while it was 13% for the treatment with plain water and 30% with the 10% bleach (Chambers, et al., 2018).

In conclusion, as demonstrated by past studies, sexual reproduction of miracle fruit offers many advantages over vegetative reproduction considering that it is possible to obtain healthier and more vigorous seedlings from them, however with the vegetative reproduction, the reproduction phase is reached so much faster. Additionally, the key to obtain higher rate of germination is to remove the seed coats and to incubate the sterilized seeds at 30°C as soon as possible after harvest as the germination rate decreases each day after harvest.

Growth and development

As reported by previous studies, miracle fruit is a very slow-growing species that takes about 3 to 4 years to reach its reproductive phase (Joyner, 2006). The vegetative phase appears to be the longest phase where in certain cases, the plant reach only 50 cm tall (Achigan-Dako, et al., 2015). During the second phase, the plant becomes mature, grows faster and can reach up to 5 meters tall in home gardens or when integrated in agroforestry systems as reported in Benin (Oumorou et al., 2010). However, new interests in the plant have incentivize researchers in finding alternatives to reduce the length of this phase. For instance, it has been demonstrated that a daily water input and application of inorganic nutrients (NPK) at a dose of 1.5 g for each element positively affected the vegetative and reproductive phase of seedlings of 15 months old. While the water treatment alone (2l daily on each seedlings) appears to be the most important factor that triggers the transition from the vegetative phase to the reproductive phase at only ~23 months old, the nutrients applications were more beneficial to the productivity of the species (longer production period and more intense fruiting) (Tchokponhoué et al., 2017). Another group of authors were successful in reducing the vegetative phase to only 24 months too by reducing the light exposure to the plants and applying organic fertilizers to the seedlings (Tchokponhoué et al., 2019).

Cultural practices

Miracle fruit is a new crop, only recently it has gained the attention of the scientific world as a crop due to its promising future in the food, pharmaceutical and cosmetic industries. Data on the cultural practices (Weed management, pest control, fertilization and other practices) are still to be investigated. Apart from few studies that investigated its botany, the effect of shade, water application and fertilization on miracle fruit, agronomic information on this crop is still very limited and more studies need to be done in other to have a broader idea on how to effectively produce it at a larger scale.

Production and potential yield

In terms of production and yield performance, information on large-scale production of this crop is scarce. Originally, knowledge about its yield potential was based on information reported for individual stands found in home gardens or farms. Such stands were reported to produce between 12-15kg/year/tree (Achigan-Dako et al., 2015), though, the information regarding the plant materials (age, type, growing environments) and the method used to collect these data were missing.

In order to advance our foundational understanding of the commercial potential for selected morphotypes developed in the USA, a study was conducted with 9 different miracle fruit types for a yearlong period. Data was collected weekly, over 52 weeks on 66 mature trees to capture the yield performance of this crop. The results revealed that each tree had the potential to produce in average 2.1 kg of fruit per year. The most performant type under the conditions of the study produced in average 2.76 kg/tree/year which is ~5 times lower than the yield reported above (Demesyeux et al., 2020). But since the data reported by Achigan-Dako (12-15 kg/tree/year) was not obtain through vigorous statistics, it cannot be used as a good reference for this crop. During this experiment, 6 different peaks of production were identified across the 52 weeks that lasted the study (Figure 4). Each of these peaks were recorded approximately every 2 months of the experiment which created what can be called "harvest windows for this crop. The total fruit (46.6kg) harvested during the first harvest window (May 21- July 12) was significantly the highest yield recorded, compared to the 11.67 kg and 15.90 obtained for harvest window 3 (September 10- November 13) and 2 (July 16- September 4) respectively (Figure 5) (Demesyeux et al., 2020).

These data confirmed that multiple harvest can be obtained from miracle fruit throughout the year and can be a valuable asset for current and future producers of this crop in the planning of their operational and marketing activities.

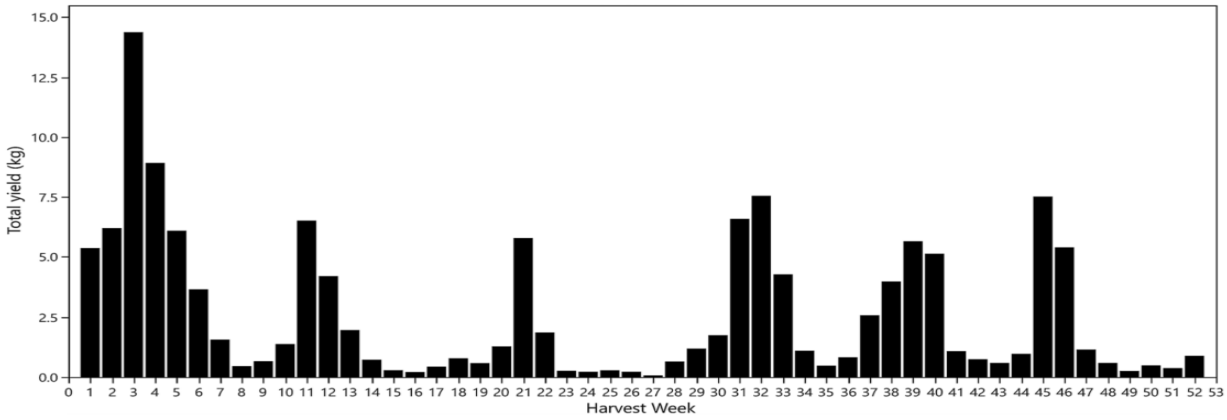

Figure 4. Total fruit yield in kg from miracle fruit for the six harvest peaks were recorded (Demesyeux et al., 2020).

Average Fruit Weight and Dimension

Each miracle fruit berry weighs in average 1.39g with a range of 0.13 to 2.96 g /fruit. This study also identified Imperial', 'Cherry', 'Scarlet', and 'Vermilion' as the morphotypes with the heaviest fruits. As for the fruits dimensions, the average fruit length was 1.99 cm while the average width was 1.18 cm. Of the nine morphotypes evaluated, 'Holly' and 'Cardinal' had the biggest fruits in terms of length and width compared to the other types (Demesyeux et al., 2020).

Potential uses of miraculin

Over the past four decades, the consumption of sugar has increased considerably among children and adults in the US. This is correlated with a growing number of people affected by chronic diseases such as obesity, diabetes type II, cardiovascular disorders and fatty liver disease (Ogden et al., 2015). This has led to the popular adoption of alternative sweeteners, many of them artificial. Unfortunately, some of these alternative sweetener compounds have negative sensory impacts or are now suspected to have negative impacts on human health (Suez et al., 2014). Thus, the demand for natural, non-caloric sweeteners such as miraculin is predicted to increase over the coming years.

Harvest window	Harvest weeks	Start date	End date	Sum yield (kg)[a]	Ave yield (kg/wk)[a]
1	8	May 5, 2018	July 12, 2018	46.61	0.088 (0.005, A)
2	8	July 16, 2018	Sept 4, 2018	15.90	0.030 (0.003, BC)
3	10	Sept 10, 2018	Nov 13, 2018	11.67	0.018 (0.002, C)
4	9	Nov 19, 2018	Jan 16, 2019	23.60	0.040 (0.004, B)
5	8	Jan 23, 2019	March 13, 2019	20.54	0.039 (0.005, B)
6	9	March 20, 2019	May 8, 2019	17.58	0.030 (0.004, BC)

[a]Data represent the sum and average yield/week of all trees by harvest window. Standard errors are shown in parentheses. Averages connected by the same letter for average yield are not significantly different ($\alpha = 0.05$)

Figure 5. Yield performance of miracle fruit by harvest windows. Total and average yield are shown for all 66 trees (Demesyeux et al., 2020).

Current medical applications

This crop has also been studied extensively in the medical field. For example, its utilization has shown positive results in helping to treat diabetic patients with insulin resistance (Chen et al., 2006). Moreover, testimonies of both medical doctors and cancer patients suggest that the ingestion of miraculin improves chemotherapy-associated taste changes, thus, improving nutrition and quality of life of these patients. It has been approved by Baptist Health South Florida Hospital as the first and only dietary supplement to be distributed in their hospital network. (Wilken and Satiroff, 2012; Miracle Fruit Farm, 2019).

Economic importance and potential for production in Haiti

Miracle fruit, as the unique natural source of miraculin is gaining a lot of interest nowadays because of its promising economic potential to serve as an alternative to synthetic sugar and as a dietetic supplement for diabetic patients (Wong & Kern, 2011). Its taste altering property is being evaluated and trialed as a natural flavor enhancement to help cancer patients that went through radiation or chemotherapy to regain their palatability. Although utilized also in the food and cosmetic industry, miracle fruit is mostly valued in the pharmaceutical industry (Achigan-Dako et al., 2015). This crop is being sold, mainly virtually on many forms (Plants, fresh fruits, powder, dry fruits coated with miracle fruit powder and flavor enhancement tablets) at extensive prices. For instance, fresh fruits are sold in small bags containing 30 fruits for approximately USD30, while a kg of powder can reach up to USD2500 (https://www.miraclefruitfarm.com/shop).

This crop offers a great opportunity to diversify income sources and to empower smallholder farmers in developing countries such as Haiti (Fandohan et al., 2017). Due to its tropical climate and rich soils, many regions in Haiti are suitable for the crop's production. Since information regarding the optimal temperature ranges for the growth and reproduction of this crop is missing, it would be recommended to concentrate the

production in hot and humid lowlands as suggested by Milhet and Costes 1984. Moreover, considering that it grows better under partial shade, integrating miracle fruit in agroforestry systems with other tropical fruits such as mango and avocado as suggested by (Oumorou et al., 2010), could help diversify income sources in the household and contribute to soil conservation as a perennial crop.

Miracle fruit could help alleviate poverty in the country as well as stated by Achigan-Dako, 2015. At the current price this fruit is being sold online (~1$/berry) and its average yield, a farmer can hope to earn more than 1000$/tree/year with the proper marketing. Additionally, producing the crop in country, would increase its availability for the population and help improving the life of the increasing number of diabetic and cancer patients.

Conclusion

Synsepalum dulcificum is a tropical crop with great potential. It can offer many benefits to the world population in terms of its medicinal properties. However, there is a pressing need to expand our knowledge on its horticultural and environmental requirements for a better exploitation of its properties. This crop could serve as an alternative income source for our farmers and could represent an opportunity to educate Haiti's population, especially those affected by chronic diseases such as diabetes on alternative natural sweetener to include in their diet to promote a healthier lifestyle.

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