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Non-microbiological shelf life of two plantain (*Musa paradisiaca*) cultivars[1,2]

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ABSTRACT

Research conducted at the USDA Tropical Agricultural Research Station evaluated the agronomic potential of Maiden plantain, assessing the non-microbiological shelf life of Maiden and Maricongo cultivars to determine whether Maiden would be suitable to replace or supplement Maricongo. Data showed that Maiden averaged 26.2 days to reach maturity stage 7, while Maricongo required 22.7 days. However, both cultivars took around 40 days to reach senescence. In other parameters evaluated, with few exceptions, no significant differences (P>0.05) were found between Maiden and Maricongo. Data gathered in this study suggest that Maiden could be an adequate replacement or supplement to Maricongo.

Key words: shelf life, plantain, *Musa paradisiaca*

Resumen

Vida útil no-microbiológica de dos cultivares de plátano (*Musa paradisiaca*)

Investigaciones realizadas en la Estación de Investigación en Agricultura Tropical del Departamento de Agricultura de EE.UU. (USDA-TARS, por sus

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siglas en inglés) evaluaron el potencial agronómico del plátano Maiden. Este estudio evaluó la vida útil no-microbiológica de los cultivares Maiden y Maricongo para determinar si Maiden es adecuado para remplazar o suplementar a Maricongo. Los datos demostraron que Maiden tardó 26.2 días en promedio para alcanzar la etapa 7 de madurez mientras que Maricongo requirió 22.7 días. Sin embargo, ambos cultivares tomaron cerca de 40 días para alcanzar la senescencia. En términos de los otros parámetros evaluados, con pocas excepciones, no se identificaron diferencias significativas (P>0.05) entre Maiden y Maricongo. Los datos recopilados sugieren que Maiden puede ser un remplazo o suplemento adecuado para Maricongo.

Palabras clave: vida útil, plátano, *Musa paradisiaca*

INTRODUCTION

Plantain is a staple food in many countries and a crop of great economic importance in Puerto Rico (Cortés and Gayol, 2006; Cortés, 2016). According to FAOSTAT data (accessed September 2021), worldwide gross production of plantains peaked at $104.8 billion in 2014 and decreased to an average of $84.1 billion for the 2015-2018 period. In Puerto Rico, plantain production contributed an average $71.2 million to the annual gross income for the period 2013-14 to 2016-17 (Department of Agriculture of Puerto Rico, estadisticas.pr, accessed September 2021).

An unpublished report by Rivera and González (2015)[6] established that Maiden plantain production can assure a continued supply of product to processing plants, which are adversely affected by shortages. Thus, supplying Maiden plantains to processors would leave the fresh market to Maricongo, the cultivar of greatest importance in Puerto Rico. Rivera and González (2015) explained that product quality (i.e., size) determines market price when there is an abundance of supply. Smaller plantains are considered second grade and can negatively impact the fresh market price of a first-grade product. Under this scenario, processing plants have access to product at fair prices. In times of product shortages, however, farmers supply first and second grade product to the highest bidder, usually to meet fresh market demand. Therefore, processing plants without a pre-negotiated purchase agreement have difficulty getting product from local suppliers and must rely on imported product.

Studies conducted at the USDA Tropical Agriculture Research Station (TARS) on the agronomic characteristics of Maiden plantains in Puerto Rico (Irizarry et al., 2001; Goenaga and Irizarry, 2006) showed

[6]Rivera, L.E. and A. González, 2015. Evaluación del plátano "Maiden" en la costa sur de Puerto Rico. Agricultural Experiment Station, University of Puerto Rico – Mayagüez. Personal communication.

that Maiden plantains produce more (but smaller) fruits per bunch than Maricongo, resulting in a heavier bunch (i.e., 29.6 kg for Maiden versus 21.4 kg for Maricongo).

As part of the University of Puerto Rico Agricultural Experiment Station (UPRM-AES) Project H-402, researchers have planted Maiden plantain since 2014 to produce seeds to foster commercial plantations (personal communication, Rivera and González, 2016)[7]. In the process, they collected agronomical data on Maiden plantain production and obtained results comparable to those reported by the USDA-TARS researchers.

Factors such as durability, disease resistance and certain agronomical characteristics determine the success of introducing new plantain cultivars to the market. Dadzie and Orchard (1997) state that green life potential (how long plantains remain green) plays an important role in market acceptability of the product because the length of "green" time facilitates commercialization and reduces postharvest losses. Cortés and Gayol (2006) said that Puerto Rico's plantain industry must define alternatives that strengthen and expand the processed plantain market. Furthermore, Cortes (2016) maintained Puerto Rico lacks a formal plantain processing industry, and the development of such business would reduce imports, foster agricultural production, generate employment and increase agricultural income.

Hence, our main objective was to evaluate the potential of Maiden plantain to replace or supplement Maricongo. More specifically, data herein seeks to compare Maiden and Maricongo cultivars in terms of non-microbiological shelf-life parameters such as maturity index, weight loss, skin and pulp color, pH, °Brix and enzymatic activity.

MATERIALS AND METHODS

Plantain clusters of Maiden and Maricongo cultivars, purchased from a local commercial farm in Moca, Puerto Rico, were identified by cultivar and transported to the laboratory facilities at University of Puerto Rico in Mayagüez. Maiden and Maricongo samples were grown following similar recommended practices and randomly harvested for both replicates of the experiment (i.e., September and October 2018). No additional treatment was applied to samples. At the lab, fingers were separated, washed, sorted (to remove any damaged product) and stored unpacked over wire shelving at 20° C until evaluation. Tests performed

[7]Rivera, L.E. and A. González, 2016. Production data for Maiden and Maricongo plantains. Agricultural Experiment Station, University of Puerto Rico – Mayagüez. Personal communication.

included maturation index using the hedonic scale, pulp and skin color using a colorimeter, pulp pH, pulp ºBrix, weight loss, and enzymatic (i.e., peroxidase, PPO) activity. Samples for maturity index determination and weight loss were kept separate from the pool of plantains to assure using the same set of fruits throughout the storage period. Maturity index and weight loss evaluation (N=8) took place every four days until senescence. For other tests, 16 samples were randomly taken from the pool of plantains when they reached the desired maturity stage. Data gathered was analyzed using InfoStat version 3.0.

Maturity index determination

Evaluation of maturity index used the USDA-BAN-C-1 hedonic scale (USDA-AMS, 2004) following instructions in the Market Inspection Instructions for Bananas (USDA-AMS, 2004) with a modification. The modification consisted of regrouping the seven stages of the scale into four. Namely, the “green stage” included maturity indexes 1 and 2, “mature-green stage” included indexes 3 and 4, “ripe stage” included indexes 5 and 6, and maturity indexes 7 and above were labeled “overripe stage”. Eight samples of each cultivar were randomly selected and evaluated every four days until senescence.

Weight loss

Samples used for maturity index determination were numbered and weighed (VWR 214B) on each evaluation day until senescence. Weight loss was calculated as a percentage of the initial weight.

Skin and pulp color

Color was determined using a handheld colorimeter (HunterLAB Miniscan)[8] configured to measure the tristimulus parameters L*a*b* for a 10° observer using D65 illuminant. Hue [i.e., $H = \tan^{-1}(b^*/a^*)$] and chroma [i.e., $C = \sqrt{(a^{*2}+b^{*2})}$] were calculated from measured data. Skin and pulp color measurements were taken at the center and close to the extremes (i.e., about 2.5 cm from the tip) of each sample. For pulp color, 1.3 cm thick rings were cut at the three measurement sites to expose (and immediately measure) the pulp.

Pulp pH and °Brix

Pulp pH measurements required using a standardized potentiometer (Accumet Benchtop Meter AB 150). A 30-g sample taken from each

[8]Mention of trade names or commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the University of Puerto Rico.

sample was mixed with 90 mL of distilled water for two minutes and filtered. The meter's electrode was introduced into the filtrate until the displayed measurement stabilized and the pH data taken. Next, a portion of the filtrate was placed on the reception glass of a digital refractometer (Palm Abbe PA202) to measure ºBrix as per A.O.A.C. 93, 1290 (A.O.A.C., 1990).

Enzymatic activity

Enzymatic activity was assessed using a qualitative peroxidase test following the application of one of four different browning prevention treatments. Applied treatments consisted of 1% m/v citric acid solution with 0, 0.25, 0.50 or 1% m/v sodium bisulfite in distilled water (Muñoz-Rodríguez, 2012). Slices of plantain peels were immersed in the corresponding treatment solutions for up to 16 minutes. Every two minutes, a sample was removed from the treatment solution to evaluate enzymatic activity.

For the test, 5 g of the treated sample was weighed (Mettler PC16), mashed and mixed with 5 mL of distilled water. The mixture was transferred to a 10 mL test tube, mixed with 1 mL of a guaiacol solution (1% guaiacol in 95% ethanol) followed by 1 mL of 1% hydrogen peroxide solution, capped and shaken slightly. A positive result (active enzyme) was recorded if the solution inside the tube turned reddish within a five-minute period. Otherwise, a negative result was recorded.

RESULTS AND DISCUSSION

Maturity index

Banana maturation scale USDA-BAN-C-1 provided a seven-point visual reference to evaluate the commercial maturity index of plantain samples. Other visual references further extend the scale to 10 points and include plantains (or bananas) exhibiting skin colors ranging from 50% black (index 8) to 100% black (index 10) (Baiyeri, 2001). During the observation period, it was noted that the established four-day evaluation interval was excessive as some samples were rushed through maturity indexes too quickly. Thus, data gathered was grouped into the four previously defined stages to provide meaningful results.

Figure 1 shows the average number of days Maiden and Maricongo samples remained at the modified maturity stage. Average shelf life was 42.8 and 40.0 days (to senescence) for Maiden and Maricongo, respectively. Data showed no significant difference ($P>0.05$) between cultivars at any of the maturation stages, except at the mature-green

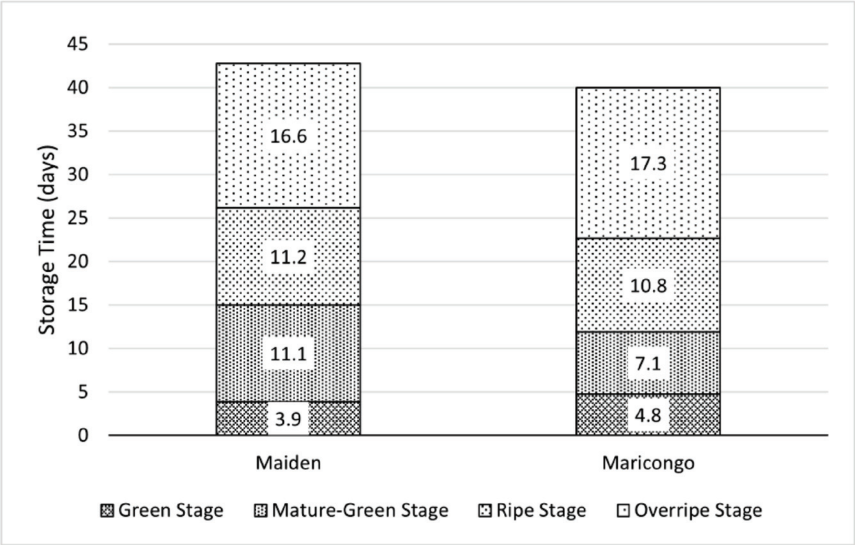


FIGURE 1. Average time samples remained at a given maturity stage.

stage in which Maiden remained 11.1 days compared with 7.1 for Maricongo. Maiden took 26.2 days on average to reach maturity stage 7 while Maricongo required 22.7 days.

Weight loss

Weight changes during storage of fruits and vegetables have been attributed to moisture loss due to transpiration (Ben-Yehoshua and Rodov, 2003; Mohapatra et al., 2016; Adi et al., 2019). Observed experimental data appears in Figure 2. There was no significant difference between cultivars. Rate of weight loss was 1.77% per storage day (R^2 = 0.97) reaching 24.7% on day 16 and 37.0% on day 20. Similar weight loss (e.g., about 25% in 18 days) has been reported (Hailu et al., 2014; Adi et al., 2019). Hailu et al. (2014) reported weight loss at around 9% after 36 storage days when packed in polyethylene bags (i.e., LDPE or HDPE).

Pulp and skin color

The measurement system L*a*b* represents a tridimensional color space in cylindrical coordinates. L* ranges from black (L = 0) to white (L = 100) while a* and b* denote color planes (i.e., green = -a*, red = a*, blue = -b*, yellow = b*) of increasing intensity proportional to the cylinder's radius. Colors around the cylinder's axis fade away and are perceived as shades of grey. Hue and chroma derive from a* and b* data and indicate color tone and saturation (i.e., intensity), respectively.

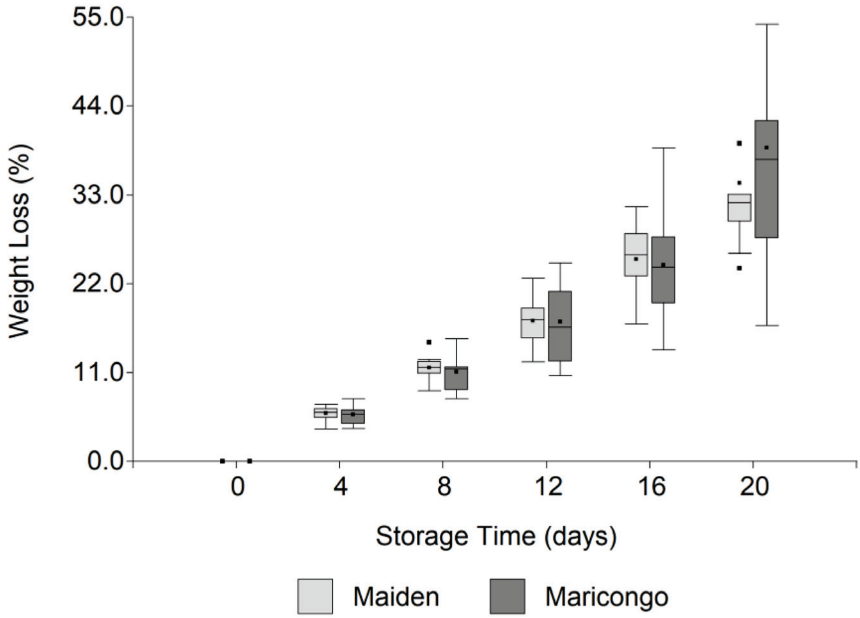


FIGURE 2. Weight loss during storage (box plot of mean ± 3 standard deviations).

Skin color data appears in Table 1. As fruit ripens, the color turns from light green (i.e., Hue ~1.8 corresponding to yellow green, chroma ~49) at stage 1-2 to intense yellow (Hue ~1.4, chroma ~58) in stage 5-6. As dark spots appear and skin browns at stage 7, Hue remains in the yellow range (i.e., Hue ~1.35) but color saturation increases (specifically a* increases to ~12.3). Color changes observed in this research agree with those reported by Ding et al. (2007), Adi et al. (2019) and Moreno et al. (2021). With few exceptions, no significant differences in skin color were identified between Maiden and Maricongo.

Pulp color data in Table 2 show that Hue values are practically the same through maturation for both Maiden and Maricongo. Pulp color significantly intensifies (i.e., chroma increases) and darkens (i.e., L* decreases) as fruit ripens, shifting from a dull whitish yellow to light yellow. These results are similar to those in other research (Salvador et al., 2007; Cordero, 2010; Adi et al., 2019; Borges et al., 2019). Enriquez-Valencia et al. (2020) states that pulp color changes relate to content changes of carotenoids and phenolic compounds, and polyphenol oxidase activity.

Data in Table 2 show that the initial and final pulp colors are similar for Maiden and Maricongo. Their only difference is the rate of pulp

TABLE 1.—*Differences in skin color between cultivars Maricongo and Maiden at different maturity stages*[1].

Parameter	Cultivar	Maturity Stage			
		Green	Mature-Green	Ripe	Overripe
L*	Maiden	51.68^{A}_{a}	58.69_{b}	62.58_{b}	59.97_{b}
	Maricongo	54.83^{B}_{a}	58.69_{a}	64.09_{b}	58.91_{a}
a*	Maiden	-11.96_{a}	-0.99_{b}	10.85_{c}	12.35_{c}
	Maricongo	-11.32_{a}	-1.69_{b}	9.96_{c}	12.33_{d}
b*	Maiden	47.93_{a}	51.18_{a}	57.44_{a}	59.73^{B}_{b}
	Maricongo	46.77_{a}	48.35_{a}	58.06_{b}	55.27^{A}_{b}
Hue	Maiden	1.82_{a}	1.59_{b}	1.38_{c}	1.37_{c}
	Maricongo	1.81_{a}	1.61_{b}	1.40_{c}	1.35_{c}
Chroma	Maiden	49.42_{a}	51.37_{a}	58.46_{b}	61.03_{b}
	Maricongo	48.15_{a}	48.66_{a}	59.95_{b}	56.68_{b}

[1]Maturity stages: 1-2 = green; 3-4 = mature-green; 5-6 = ripe; ≥7 = overripe
For each parameter, values with different superscripts along the column and values with different subscripts along the row are significantly different (P<0.05).

color intensification. At stage 1-2, cultivars exhibit similar pulp color. For Maiden, color gradually intensifies through stage 3-4 to final values achieved in stage 5-6. By contrast, Maricongo pulp color during stage 3-4 is like that of stage 1-2, but changes rapidly to reach its final color at stage 5-6. The gradual color shift during Maiden's stage 3-4 is the only significant difference observed between the cultivars.

pH and °Brix

According to Quiceno et al. (2014), while organic acid content decreases during ripening in most fruits, the opposite occurs in plan-

TABLE 2.—*Differences in pulp color between cultivars Maricongo and Maiden at different maturity stage*[1].

Parameter	Cultivar	Maturity Stage			
		Green	Mature-Green	Ripe	Overripe
L*	Maiden	81.19_{a}	78.40^{A}_{b}	73.36^{A}_{c}	73.72_{c}
	Maricongo	81.29_{a}	80.46^{B}_{a}	75.62^{B}_{b}	74.95_{b}
Hue	Maiden	1.25	1.24	1.25^{A}	1.24
	Maricongo	1.25	1.26	1.23^{B}	1.25
Chroma	Maiden	40.71_{a}	44.91^{A}_{b}	50.49_{c}	50.10_{c}
	Maricongo	40.26_{a}	41.14^{B}_{a}	49.22_{b}	49.41_{b}

[1]Maturity stages: 1-2 = green; 3-4 = mature-green; 5-6 = ripe; ≥7 = overripe
For each parameter, values with different superscripts along the column and values with different subscripts along the row are significantly different (P<0.05).

tains. Such behavior enables acidity to be used as a maturity indicator in plantains (Cayón et al., 2000; Dadzie and Orchard, 1997).

Table 3 shows pH values decreasing from 6.1 for stage 1-2 to 4.4 at stage 5-6. As seen in pulp color, Maiden initiates changes before Maricongo does. Consequently, significant differences between the cultivars are only observed in stage 3-4. These results agree with those reported by Barrera et al. (2010), Quiceno et al. (2014) and Arrieta et al. (2006).

Soluble solids content represents an important quality criterion of fruits since they increase as the fruit ripens (Dadzie and Ochard, 1997). Traditionally, ºBrix data has been used as an indicator of soluble solids, particularly sugar content estimated from the expressed juice. It must be understood, however, that ºBrix data can also be affected by pectin, organic acids, amino acids and other soluble solids present in the juice sample (Kleinhenz and Bumgarner, 2013).

Plantains are starchy crops. As such, carbohydrates comprise approximately 70% of the total solids content. For green plantains, roughly 83% of the carbohydrates are starch. As the fruit ripens, starch content decreases to about 66% while sugars increase from 1.8 to 17% because of starch degradation (Ketiku, 1973). The increasing trend in ºBrix data (Table 3) agrees with the expected behavior reported in the literature for fruits and vegetables (Dadzie and Ochard, 1997; Carvalho et al., 2009; Arrieta et al., 2006; Barrera et al., 2010; Cordero, 2010; Adi et al., 2019). Cultivars showed no significant difference in ºBrix data, except for stage 3-4 (as noted for pH and pulp color).

Enzymatic activity

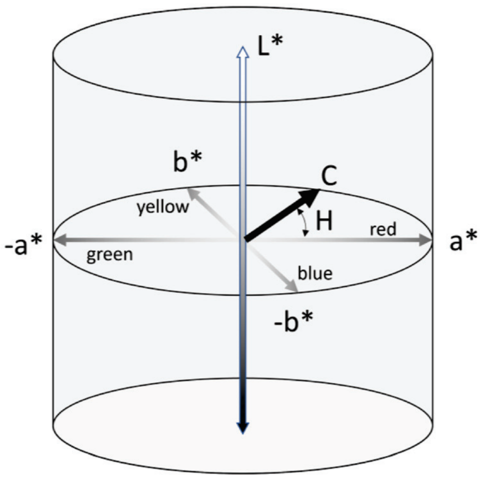
Enzyme activity is responsible for the transformation of phenolic compounds into o-quinones that polymerize to dark pigments (Arnnok et al., 2010). One such enzyme is polyphenol oxidase (PPO).

TABLE 3.—*Differences in pH and ºBrix between cultivars Maricongo and Maiden at different maturity stages*[1].

		Maturity Stages			
Parameter	Cultivar	Green	Mature-Green	Ripe	Overripe
pH	Maiden	6.08_a	4.98^A_b	4.44_c	4.42_c
	Maricongo	6.10_a	5.40^B_b	4.42_c	4.37_c
ºBrix	Maiden	6.7_a	14.9^A_b	28.1_c	30.9_d
	Maricongo	7.8_a	10.7^B_a	28.1_b	29.9_b

[1]Maturity stages: 1-2 = green; 3-4 = mature-green; 5-6 = ripe; [3]7 = overripe

For each parameter, values with different superscripts along the column and values with different subscripts along the row are significantly different (P<0.05).



$$Chroma = \sqrt{a*^2 + b*^2}$$

$$Hue = tan^{-1}\left(\frac{b*}{a*}\right)$$

Color	Hue (radians)
Red	0 to 1.047
Yellow	1.047 to 2.094
Green	2.094 to 3.142
Cyan	3.142 to 4.189
Blue	4.189 to 5.246
Magenta	5.246 to 6.283

FIGURE 3. Color measurement system.

In plantains, PPO facilitates the formation of melamine pigments upon exposure of the pulp to oxygen (Archer and Palmer, 1975). The use of acid and/or salt (e.g., sodium bisulfite) solutions to control enzymatic activity is well documented (Eissa et al., 2006; Lee, 2007; Muñoz-Rodríguez, 2012; Ioannou and Ghoul, 2013; Moon et al., 2020).

This study considered four citric acid solutions with different levels of sodium bisulfite (i.e., 0, 0.25, 0.5 and 1.0%) based on the research by Muñoz-Rodríguez (2012) on starchy crops. Even after 16 minutes of immersion, the solutions with 0, 0.25 and 0.5% of sodium bisulfite proved ineffective in controlling PPO activity. Only the 1% sodium bisulfite solution deactivated the enzyme, and its effectiveness depended on the maturation stage as shown in Table 4.

TABLE 4.—*Deactivation time of PPO after immersion in 1% citric acid solution containing 1% sodium bisulfite.*

	Maturity Stage			
Cultivar	Green	Mature-Green	Ripe	Overripe
Maiden	6.0_a	11.0^B_b	13.0_c	NI
Maricongo	6.4_a	12.0^A_b	NI	NI

For each parameter, values with different superscripts along the column and values with different subscripts along the row are significantly different (P<0.05). NI = No inactivation.

CONCLUSION

This study strived to compare the non-microbiological shelf life of Maiden and Maricongo cultivars. In general terms, the cultivars performed similarly in all evaluations. Maiden averaged 26.2 days to reach maturity stage 7, while Maricongo required 22.7 days. However, both cultivars took around 40 days to reach senescence. Weight loss rate was around 1.77% per day reaching 24.7% after 16 days of storage and 37.0% after 20 days. With few exceptions, no significant differences in skin color, pulp color, pulp pH, or ºBrix were identified between Maiden and Maricongo. An interesting observation of this data is that Maiden gradually changes as it ripens from the green stage to the ripe stage, while Maricongo maintains similar characteristics during the green and mature-green stages, changing rapidly as it enters the ripe stage. In terms of enzymatic activity, only the 1% sodium bisulfite solution deactivated the PPO enzyme, and its effectiveness depended on the maturation stage of the fruit. Data gathered in this study suggests that Maiden could be an adequate replacement or supplement to Maricongo.

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