Journal of Agricultural Sciences (Belgrade)
Vol. 68, No. 3, 2023
Pages 283-300
https://doi.org/10.2298/JAS2303283E
UDC: 635.615(669.1)
Original scientific paper

GROWTH, YIELD AND VARIANCE COMPONENTS OF WATERMELON (*CITRULLUS LANATUS*) GROWN ON LIME ($CACO_3$)-AMENDED ACIDIC SOIL OF SOUTH-EASTERN NIGERIA

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Abstract: A field experiment was conducted to assess the growth and yield of watermelon *Citrullus lanatus* [(Thunb.) Matsum. & Nakai] under acidic soil conditions in Calabar, Cross River State, Nigeria. The experiment was a 3 × 3 factorial experiment laid in a randomized complete block design (RCBD) with three replications. The factors studied were varieties (Heracles F_1, Kaolack and Sugar Baby), lime rates (0 t ha^{-1}, 2.7 t ha^{-1} and 5.7 t ha^{-1}), and their interactions on watermelon growth and yield traits. Heracles F_1 and Kaolack outperformed Sugar Baby ($p \leq 0.05$) regarding growth and yield traits. Lime rates of 2.7 t ha^{-1} and 5.7 t ha^{-1} increased the initial soil pH range (4.6–4.9) by 21.74% (5.4–5.8) and 43.48% (6.4–6.7), respectively. These rates improved the soil pH to a range suitable for watermelon cultivation in the study area. Vine length, number of leaves, transverse and longitudinal sections of the fruits and sugar content of the fruits had ≥ 50% heritability, a useful index in the selection of choice growth and yield traits in watermelon. Overall, GAM was greater than GA for each of the traits except for the total number of seeds per fruit. Multi-location studies are recommended to give further insights to this pilot study.

Key words: brix, fruits, heritability, hybrid, lime, soil acidity, ultisol, watermelon.

Introduction

Watermelon (*Citrullus lanatus* (Thunb.) Matsum. & Nakai) is a warm-season crop and an important member of the cucurbit family, propagated primarily by seeds (van der Vossen et al., 2004). It is grown throughout India and other tropical countries, including Nigeria (Fehér, 1993). Watermelon is one of the most widely cultivated crops in the world (Huh et al., 2008). The crop, watermelon, refers to the fruit and plant of a vine-like (climber or trailer) herb (TFNet, 2016). The center of

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origin of watermelon has been traced to the Kalahari and Sahara deserts in Africa (Jarret et al., 1996). Its first harvest was documented in Egypt 5,000 years ago and subsequently expanded to other parts of the world (Strauss, 2015). In 2021, China was the leading global watermelon producer (60.8 MT), followed by Turkey (3.47 MT) and India (3.25 MT) (FAOSTAT, 2022). According to Balakrishnan et al. (2015), the fruit of watermelon has a water content of about 93%, which gives it the name 'watermelon'. The term 'melon' comes from the fact that the fruit is large and round and has a sweet, pulpy flesh. The scientific name of watermelon stems from Greek and Latin roots; the *'Citrullus'* is derived from the Greek word 'citrus' which refers to the fruit (Maynard, 2001). The Latin '*lanatus'* means woolly and refers to the small hairs on the stems and leaves of the plant, which has both nutritional and medicinal values (Gwana et al., 2014). The fruit's skin color can vary from white to shades of green and possibly marbled or striped. This genus contains a total of four species (Renner et al., 2014) and watermelon belongs to *Citrullus lanatus* because of its pink/red or yellow flesh and black seeds (Montesinos, 2006). It is important to differentiate between *Citrullus lanatus* (bigger fruits) and *Citrullus colocynthis* (L.) (smaller fruits), both commonly known as watermelons, which are excellent sources of high-quality proteins and edible oils used in cooking for human and cattle nutrition in some African and Middle Eastern American countries (Milovanović et al., 2009).

Watermelon is rich in vitamins A, B and C, amino acids and carotenoid lycopene (Alam et al., 2013; Maoto et al., 2019). Vitamin B is mostly responsible for generating energy in the body (Muhammad et al., 2014). Thus, consuming watermelon may increase energy levels. Vitamin C is an essential nutrient for humans because it helps in the synthesis of collagen and protects various tissues from oxidative stress (Akbari and Jelodar, 2013; Devaki and Raveendran, 2017). It also contains potassium, which helps control blood pressure and possibly prevent strokes (Adekunle et al., 2005). Lycopene, a red pigment from the carotenoid class present in only a few fruits and vegetables, is a potent oxygen radical collector and a highly effective antioxidant (Gerster, 1997). *Citrullus lanatus* prefers a warm, dry climate with an average daily temperature ranging from 22ºC to 30ºC (FAO, 2001). Watermelons can be grown on a wide range of soil types. Although sandy soils are preferred, the highest yields are usually obtained on well-drained sandy-loam soils and soil pH (in H_2O) should be about 5.8–6.2 for optimum yield (Watermelon Production Guideline, 2014). Watermelon has a smooth outer rind and a juicy, sweet, usually red, internal flesh. It can be used as a fresh salad, dessert, snack, and for decorative purposes (Perkins-Veazie et al., 2012). Fruity beverages may also be made from its juice.

Watermelon fruits may weigh 1–100 kg or more (e.g., 'Carolina Cross' – Gusmini and Wehner, 2007), but most commercially available watermelons weigh between 3 and 13 kg (Wehner, 2008). The sugar content and the sweetness are the critical factors in determining the quality of many watermelon varieties. Watermelon is known to be low in calories, but it is a highly nutritious and thirst-quenching fruit (Okonmah et al., 2011). Watermelon is a good source of carotenoids and lycopene, which have been shown to protect against a growing list of cancers (Cho et al., 2004). Over the past few decades, the presence of an appreciable amount of lycopene in watermelon has motivated farmers and fruit and vegetable producers to grow mainly red-fleshed watermelon varieties. A total of 1,200 cultivars of watermelon are produced worldwide (Helyes et al., 2009). Watermelon yield performance differs among cultivars due to variation in vine length, number of branches, number of male and female flowers, fruit number and weight (Mrema and Maerere, 2018). The critical periods in watermelon cultivation are planting, vegetative growth, flowering and fruiting.

Agriculture serves as the backbone of developing economies. Due to environmental factors such as soil salinization, erosion, and acidification, agricultural land is increasingly degraded and poorly suited for large-scale agricultural production (Jones et al., 2013; FAO and ITPS, 2015). Soil fertility is affected by soil acidity due to nutrient deficiencies (P, Ca and Mg) and the increased presence of certain nutrient elements such as soluble Al^{3+} and Mn^{2+} at phytotoxic levels. Liming is a longstanding and standard management practice used to maintain optimal soil pH for crop production (Goulding, 2015). The application of lime to acid soils could reduce Al^{3+} and Mn^{2+} toxicity, while improving pH, Ca, Mg and increasing P uptake in soils with high P fixation and plant root systems (Black, 1992). Liming has a positive effect on the yield of most arable crops. However, there are distinct differences between crops in yield responses to lime (Cifu et al., 2004) because crop varieties may have different tolerance for soil acidity.

The soils of the tropical rainforest of Nigeria are very acidic, deficient in micronutrients, and often result in low yields without any improvement or modification. Watermelons may be grown on a wide variety of soil types, although sandy soils are preferred. It has a long prostrate growth habit and therefore requires adequate spacing on well-drained sandy-loam soils that are rich in organic matter with good moisture retention (Lawal, 2000). Watermelons can tolerate a certain level of soil acidity (5.5 to 6.7), but the pH of the soil should not be less than 5.5 for good yields. Cultivation in heavy textured soils results in a slower crop development and cracked fruits (FAO, 2010).

During the early 2018 cropping season (March–April), 95% to 100% of immature fruits of all watermelon varieties planted split before maturity at the University of Calabar Teaching and Research Farm and yield loss was over 96%. Given that there are speculations on the influence of an interplay of weather conditions and soil pH on watermelon growth and yield, it was hypothesized that the application of lime and the cultivation of watermelon during the late growing season (August–September) could influence (regulate) soil pH in favor of watermelon cultivation.

Thus, this study was designed to assess the growth and fruit yield of watermelon on the acidic soil of Calabar during the second cropping season, under the influence of lime. The objective of the study was to compare the changes in growth and yield characteristics of watermelon genotypes in response to the lime amendment on the acidic soils of Calabar. This was done by examining the growth and yield performances of watermelon genotypes on limed and non-limed acidic soils and estimating the extent of the inherent (genetic) and environmental-induced (soil pH-dependent) variations in the growth and yield responses of watermelon genotypes in Calabar.

Material and Methods

The experiment was performed at the Experimental Farm of the University of Calabar, Cross River State. Calabar is located in the south-eastern rainforest agroecological zone of Nigeria and lies between latitude 4.5–5.2^0 N, longitude 8.0–8.3^0 E and about 39 m above sea level. Cutting and scrubbing were done by a machete. Moderate stumping, where necessary, was manually done with spades, a cutlass and an axe. Neither the application of chemical herbicides nor bush burning was carried out during the process. The cuts and debris were left to decompose within two weeks and plowed into the soil during manual tillage. Representative soil samples were taken at random from a depth of up to 30 cm of topsoil. Three samples were taken from each of the three blocks using a soil auger (carefully cleaned of soil and possible debris between sampling). The nine soil samples were grouped (block-wise) into three composite samples for physical and chemical analyses of soil properties.

The lime type used for the study was agricultural lime with the chemical formula $CaCO_3$ and a neutralizing value of 100 (Bolan et al., 2003). It was acquired through the Cross River State Agricultural Development Program Office in Calabar. Three lime rates were used for the experiment: 0 t ha^{-1}, 2.7 t ha^{-1} and 5.7 t ha^{-1}. The watermelon seeds were sourced from Technisem® seed through the Cross River State Agricultural Development Seed Unit. The three watermelon varieties obtained were: Heracles F_1 hybrid, Kaolack and Sugar Baby.

The experimental design was a 3 × 3 (i.e., three watermelon genotypes and three levels of lime application) factorial design in a randomized complete block design (RCBD) with three blocks (replicates) on a 15 m × 45 m experimental plot. Each treatment plot measured 4 m × 4 m. Lime was applied in hollow holes (30 cm in diameter and 15 cm deep). After 7 days of lime application, three seeds each of the watermelon varieties were planted on September 11, 2018 at a spacing of 1 m x 1m. Thinning was done at 7 days after planting; leaving one plant per hill, resulting in 16 stands per treatment plot and a plant population of 10,000 stands per hectare. The following agronomic data were collected from four labelled plants in the net plot (2 m × 2 m): vine length (cm), number of leaves per plant, days to 50% flowering, number of fruits per plant, cross-section of mature fruits (cm) (i.e., fruit width), longitudinal section (cm) (i.e., fruit length), fresh weight per fruit (kg), fresh fruit yield (t ha^{-1}), fruit rind thickness (cm), number of seeds from mature fruits, total soluble sugar content (Brix).

Data collected were analyzed with the GenStat package (16^{th} edition) using the randomized complete block design (RCBD) with three replications. Means of significant F-tests for variety and lime rates were compared using a Fisher's protected least significant difference (LSD) at the 95% confidence level. The means of the interaction effects (variety x lime rate) were compared using the Duncan's New Multiple Range Test (DNMRT) at a 95% confidence level.

Plant Breeding Tools Version 1.4 was used for the estimation of genotypic, environmental and phenotypic variances (Table 1) based on the model below (Equation 1):

$$Y_{hijk} = M + L_h + R(L)_{k(h)} + G_j + GL_{hj} + e_{hijk} \quad (1)$$

where: Y_{hijk} = the measurement on plot k in environment h, block i, containing genotype j; M = the overall mean of all plots in all environments; L_h = the effect of environment h; $R(L)_{k(h)}$ = the effect of replicate i within environment h; G_j = the effect of genotype j; GL_{hj} = the interaction of genotype j with environment h and e_{hijk} = the plot residual.

Genetic advance (GA) (Allard, 1960) and genetic advance as a percentage of population means (GAM) were computed (Johnson et al., 1955).

Table 1. The variance component and the expected mean square analysis model.

Source of variation	df	MS	Expected MS
Lime rate (L)	l-1	MS_L	$\sigma_e^2 + r\sigma_{gl}^2 + g\sigma_{r(l)}^2 + rg\sigma_l^2$
Replicates within lime rate (R(L))	l(r-1)	$MS_{Rep(L)}$	$\sigma_e^2 + g\sigma_{r(l)}^2$
Genotype (variety) (G)	g-1	MS_G	$\sigma_e^2 + r\sigma_{gl}^2 + lr\sigma_g^2$
G x L interaction	(l-1) (g-1)	MS_{GL}	$\sigma_e^2 + r\sigma_{gl}^2$
Pooled error (E)	l(r-1) (g-1)	MS_E	σ_e^2

l = lime rate, g = genotype (variety), r = replicate, σ_g^2 = genotype variance, σ_l^2 = lime rate variance, σ_{gl}^2 = genotype × lime rate interaction variance, $\sigma_{r(l)}^2$ = replicate within lime rate variance, σ_e^2 = pooled error variance, df = degree of freedom, MS = mean square.

Results and Discussion

The chemical and physical properties of the soil in Table 1 show that the soil was highly acidic and needed to be limed for watermelon to thrive, as watermelon always does best in alkaline soils. The soil pH result (after lime application) at the end of the study (Figure 1) shows that the lime applied at different rates was able to increase the soil pH to 5.5 and 6.5. Lime applied at 2.7 t ha^{-1} increased soil pH from 4.6 to 5.6 and 5.7 t ha^{-1} increased soil pH to 6.6. The increase in soil pH obtained by applying lime before planting watermelon seeds significantly affected plant growth and yield attributes. Soil is a critical element of the life support system that provides several ecosystem goods and services such as carbon storage, water regulation, soil fertility and food production that impact human well-being (FAO and ITPS, 2015). In the natural environment, soil pH has an enormous influence on soil biogeochemical processes.

Table 2. Mean values of physical and chemical properties of the acidic soil used for the study.

Property	Unit	Mean value (*n* = 3)
pH (in H_2O)		4.60
Sand	g kg^{-1}	889.0
Silt	g kg^{-1}	26.7
Clay	g kg^{-1}	84.3
Texture		Loamy sand
Organic carbon	%	0.83
Total nitrogen	%	0.10
Available phosphorus	mg kg^{-1}	21.33
Exchangeable K^+	cmol (+) kg^{-1}	0.0023
Exchangeable Na^+	cmol (+) kg^{-1}	0.0035
Exchangeable Ca^{2+}	cmol (+) kg^{-1}	2.0000
Exchangeable Mg^{2+}	cmol (+) kg^{-1}	1.6700
Exchangeable Al^{3+}	cmol (+) kg^{-1}	0.0900
Exchangeable H^+	cmol (+) kg^{-1}	0.6700
Exchangeable acidity	cmol (+) kg^{-1}	0.7600
ECEC	cmol (+) kg^{-1}	4.4358
BS	%	82.87

ECEC = exchangeable cation exchange capacity, BS = base saturation, n = number of samples.

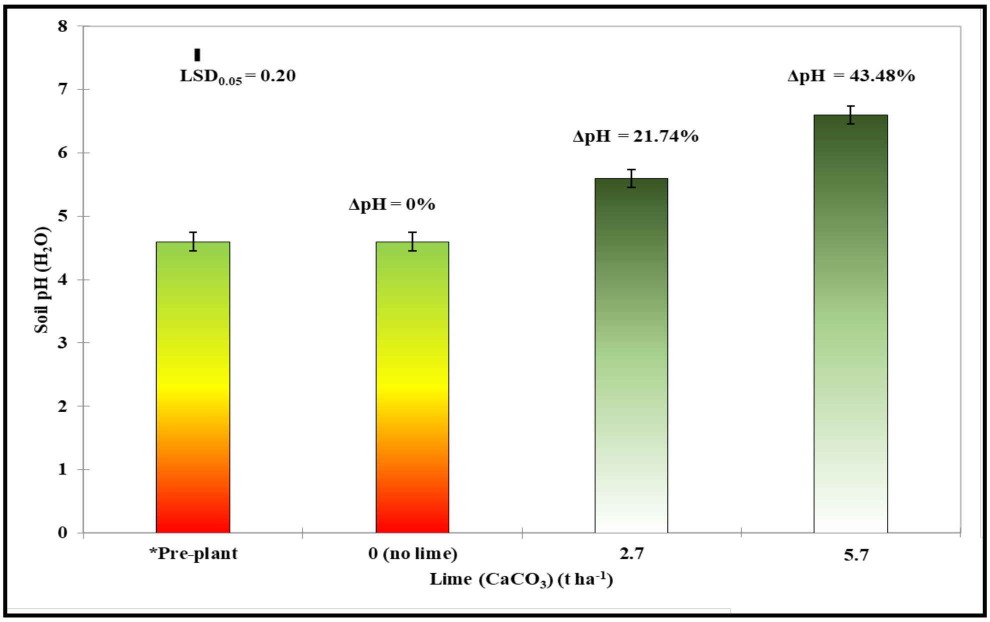

Figure 1. The soil pH (in H_2O) changes after lime application (*initial soil pH = 4.60).

The growth and yield performance of watermelon under lime-amended soil conditions are shown in Tables 3 and 4. When the interaction effect was significant, the result for the main factor (s) was not discussed. Heracles F_1 × 2.7 t ha^{-1} $CaCO_3$ produced the highest vine length (13.11 cm) and was significantly different ($p \leq 0.05$) from the other interaction effects at 21 DAP, except for Kaolack × 5.7 t ha^{-1}, Heracles F_1 × 5.7 t ha^{-1}, Kaolack × 2.7 t ha^{-1} and Heracles F_1 × 0 t ha^{-1} ($p > 0.05$). At 28 DAP, Kaolack × 5.7 t ha^{-1} produced the highest vine length (24.47 cm) but was not significantly different ($p > 0.05$) from Kaolack × 2.7 t ha^{-1} and Heracles F_1 at all lime rates. Sugar Baby × 0 t ha^{-1} produced the shortest vines at 28 DAP and was not significantly different ($p > 0.05$) from Sugar Baby × 5.7 t ha^{-1} and Sugar Baby × 2.7 t ha^{-1}. Kaolack × 5.7 t ha^{-1} (45.24 cm) still produced the longest vines at 35 DAP though was not significantly different ($p > 0.05$) from Kaolack × 2.7 t ha^{-1}, Sugar Baby × 5.7 t ha^{-1} and Heracles F_1 at all lime rates. There was no significant ($p > 0.05$) difference between Sugar Baby grown at all lime rates and Kaolack × 0 t ha^{-1}. At 42 DAP, a similar trend was observed where Kaolack × 5.7 t ha^{-1} (70.64 cm) produced the longest vines, which were not significantly different ($p > 0.05$) from Heracles F_1 at all lime rates, Kaolack × 0 t ha^{-1} and Kaolack × 2.7 t ha^{-1}, Sugar Baby × 2.7 t ha^{-1} and Sugar Baby × 5.7 t ha^{-1}. Sugar Baby grown on unamended acidic soil had the shortest vines at 42 DAP (Table 4).

Table 2. Single and interaction effects of lime and variety on vine length and number of leaves of watermelon.

Treatment	Vine length (cm)				Number of leaves			
	Days after planting				Days after planting			
	21	28	35	42	21	28	35	42
Variety								
Heracles F_1	11.63	22.31	41.05	65.61	5.13	8.43	11.70	20.00
Kaolack	10.21	20.39	37.53	61.27	4.74	8.11	10.82	18.91
Sugar Baby	7.15	15.51	28.66	50.09	4.17	6.96	8.02	15.00
$LSD_{0.05}$	*1.60*	*3.33*	*7.64*	*12.38*	*0.44*	*0.57*	*1.64*	*3.69*
Lime rate								
0 t ha^{-1}	8.30	16.43	30.23	51.84	4.32	7.46	9.09	15.70
2.7 t ha^{-1}	10.22	20.54	37.76	61.83	4.80	7.87	10.72	18.61
5.7 t ha^{-1}	10.47	21.23	39.25	63.30	4.93	8.17	10.72	19.59
$LSD_{0.05}$	*1.60*	*3.33*	*7.64*	*NS*	*0.44*	*NS*	*NS*	*NS*
Variety × lime rate								
Heracles F_1 × 0 t ha^{-1}	10.58 a	20.76 abc	40.89 ab	65.58 ab	5.06 ab	8.72 a	11.39 ab	20.00 abc
Kaolack × 0 t ha^{-1}	7.35 b	14.89 cd	26.12 cd	46.74 ab	4.00 c	6.94 c	8.28 c	13.89 bc
Sugar Baby × 0 t ha^{-1}	6.97 b	13.63 d	23.66 d	43.19 b	3.89 c	6.72 c	7.61 c	13.22 c
Heracles F_1 × 2.7 t ha^{-1}	13.11 a	24.44 a	43.26 ab	67.20 ab	5.28 a	8.56 a	12.33 a	20.67 ab
Kaolack × 2.7 t ha^{-1}	10.62 a	21.81 ab	41.22 ab	66.43 ab	4.89 ab	8.33 ab	12.17 a	20.67 ab
Sugar Baby × 2.7 t ha^{-1}	6.93 b	15.38 cd	28.81 bcd	51.87 ab	4.22 bc	6.72 c	7.67 c	14.50 bc
Heracles F_1 × 5.7 t ha^{-1}	11.21 a	21.72 ab	39.01 abc	64.06 ab	5.06 ab	8.00 ab	11.39 ab	19.33 abc
Kaolack × 5.7 t ha^{-1}	12.66 a	24.47 a	45.24 a	70.64 a	5.33 a	9.06 a	12.00 a	22.17 a
Sugar Baby × 5.7 t ha^{-1}	7.55 b	17.50 bcd	33.51 abcd	55.19 ab	4.39 bc	7.44 bc	8.78 bc	17.28 abc

Values within the same column with the same letter(s) of the alphabet were not significantly different using the Duncan's New Multiple Range Test at the 95% confidence limit. NS = not significant. $LSD_{0.05}$ = Fisher's least significant difference at the 95% confidence limit.

There was no significant difference ($p > 0.05$) for variety × lime rate at 28, 35 and 42 DAP in terms of leaf counts (Table 4). The highest number of leaves at 21 DAP was recorded for Kaolack × 5.7 t ha^{-1} (5.33) and Heracles F_1 × 2.7 t ha^{-1} (5.28). These were not significantly different ($p > 0.05$) from Heracles F_1 × 0 t ha^{-1}, Heracles F_1 × 5.7 t ha^{-1} and Kaolack × 2.7 t ha^{-1}. The lowest number of leaves was produced by Sugar Baby × 0 t ha^{-1} (13.22) and Kaolack × 0 t ha^{-1} (13.89).

However, these were not significantly different ($p > 0.05$) from Sugar Baby × 2.7 t ha^{-1} and Sugar Baby × 5.7 t ha^{-1}. At 28 DAP, Heracles F_1 (0 t ha^{-1} and 2.7 t ha^{-1}) and Kaolack (5.7 t ha^{-1}) resulted in the greatest number of leaves.

There was no significant difference ($p > 0.05$) among watermelon genotypes in days to 50% flowering time, the number of fruits harvested per plant, the average number of fruits harvested per plant and the average weight of mature fruits. Generally, the weight of the fresh fruit followed the order: Kaolack >

Heracles F_1 > Sugar Baby. Heracles F_1 × 0 t ha^{-1} (58.74 t ha^{-1}) and Kaolack × 5.7 t ha^{-1} (56.20 t ha^{-1}) produced the heaviest fresh fruits. Sugar Baby × 5.7 t ha^{-1} (16.34 t ha^{-1}) produced fresh fruits with lighter weights that were not significantly different ($p > 0.05$) from Heracles F_1 × 5.7 t ha^{-1} (Table 4). Sugar Baby × 5.7 t ha^{-1} produced fruits with smaller transverse sections, whereas Kaolack × 5.7 t ha^{-1} (14.57 cm) led to fruits with wider transverse sections, but not significantly different ($p > 0.05$) from fruits produced of the other variety × lime interactions. Heracles F_1 × 0 t ha^{-1} (18.21 cm) and Heracles F_1 × 2.7 t ha^{-1} (17.93 cm) topped in the transverse section measurements of the fruits and were not significantly different ($p > 0.05$) from Heracles F_1 × 5.7 t ha^{-1}. Sugar Baby × 5.7 t ha^{-1} fruit cross-section was significantly smaller. No significant differences ($p > 0.05$) were observed between the genotypes, lime rates and interaction levels in terms of rind thickness and the total number of seeds per fruit.

Table 4. Single and interaction effects of lime and variety on selected watermelon yield traits at harvest.

Treatment	Days to 50% flowering	Number of fruits per plant	Fresh weight per fruit (kg)	Fresh fruit yield (t ha^{-1})	Fruit width (cm)	Fruit length (cm)	Rind thickness (cm)	Total number of seeds per fruit	Sugar content (Brix)
Variety									
Heracles F_1	42.67	3.33	1.76	32.22	13.56	17.58	0.86	299.83	6.22
Kaolack	42.00	4.66	1.60	38.66	14.22	14.84	0.80	349.28	8.28
Sugar Baby	46.33	3.66	1.43	27.39	12.04	12.65	0.71	315.22	6.71
$LSD_{0.05}$	*NS*	*NS*	*NS*	*3.00*	*0.96*	*0.96*	*NS*	*NS*	*0.59*
Lime rate									
0 t ha^{-1}	43.89	4.3	1.8	41.50	13.91	15.53	0.9	332.6	6.99
2.7 t ha^{-1}	43.22	3.7	1.5	27.16	13.48	15.53	0.9	299.8	7.88
5.7 t ha^{-1}	43.89	3.7	1.5	29.62	12.43	14.02	0.7	331.9	6.33
$LSD_{0.05}$	*NS*	*NS*	*NS*	*3.00*	*0.96*	*0.96*	*NS*	*NS*	*0.59*
Variety × lime rate									
Heracles F_1 × 0 t ha^{-1}	41.00 a	5.33a	2.17a	58.74 a	14.36 a	18.21 a	0.98a	329.83a	5.83 d
Kaolack × 0 t ha^{-1}	45.33 a	3.33a	1.53a	26.34 d	13.87 a	14.07 c	0.80a	334.00a	7.43 bc
Sugar Baby × 0 t ha^{-1}	45.33 a	4.33a	1.78a	39.42 b	13.50 a	14.30 c	0.80a	334.44a	7.70 bc
Heracles F_1 × 2.7 t ha^{-1}	42.67 a	2.33a	1.78a	21.59 def	13.23 a	17.93 a	1.03a	255.33a	6.98 c
Kaolack × 2.7 t ha^{-1}	40.00 a	4.33a	1.51a	33.46 c	14.23 a	15.13 bc	0.86a	298.83a	9.11 a
Sugar Baby × 2.7 t ha^{-1}	47.00 a	4.33a	1.18a	26.42 d	12.98 a	13.51 c	0.66a	345.33a	7.56 bc
Heracles F_1 × 5.7 t ha^{-1}	44.33 a	2.33a	1.33a	16.34 def	13.08 a	16.58 ab	0.58a	314.33a	5.83 d
Kaolack × 5.7 t ha^{-1}	40.67 a	6.33a	1.75a	56.20 a	14.57 a	15.32 bc	0.73a	415.00a	8.30 ab
Sugar Baby × 5.7 t ha^{-1}	46.67 a	2.33a	1.33a	16.34 f	9.65 b	10.15 d	0.68a	266.33a	4.87 d

Values within the same column with the same letter(s) of the alphabet were not significantly different using the Duncan's New Multiple Range Test at the 95% confidence Limit. NS = not significant. $LSD_{0.05}$ = Fisher's least significant difference at the 95% confidence limit.

The sugar content of Kaolack was significantly higher (8.28 Brix) compared to other genotypes. Kaolack × 2.7 t ha^{-1} produced fruits with higher sugar content (9.11 Brix), but not significantly different ($p > 0.05$) from Kaolack × 5.7 t ha^{-1}. Sugar contents at other levels of interactions were significantly different from Sugar Baby × 5.7 t ha^{-1} with the lowest sugar content, but not significantly different ($p > 0.05$) from Heracles F_1 × 0 t ha^{-1} and Heracles F_1 × 5.7 t ha^{-1}.

Anikwe et al. (2016) reported that differences among watermelon varieties could be attributed to their inherent varietal characteristics as well as the soil condition and location of cultivation. The results obtained from the present study, where the different watermelon varieties showed significant differences in the growth trait conform with this report. Achigan-Dako (2008) has reported that there are differences in the growth and yield characteristics of watermelons. In terms of vine length and number of leaves, Heracles F_1 had the longest vines and more leaves followed by Kaolack and Sugar Baby. Achigan-Dako (2008), Uwah and Solomon (1999) also reported that the differences among watermelon varieties could be due to the genetic make-up of the watermelon varieties. This assertion aligns with the results of this study.

The application of lime to acid soils has been found to increase soil pH and therefore eliminates aluminium toxicity at pH > 5.5 by precipitating Al, making it unavailable for plant uptake (Meriño-Gergichevich et al., 2010). Hue and Mai (2002) have reported that adequate application of lime raises soil pH to 5.7 or higher, which is essential for normal watermelon growth. The results of the study showed that lime applied to the acid soil to raise the soil pH to 5.5 and 6.5 had a significant influence on the growth traits of the watermelon varieties compared to the area where no lime was applied. Lime applied at 5.7 t ha^{-1} raised the soil pH to 6.6, causing the vines to grow significantly longer and have a greater number of leaves, followed by lime applied at 2.7 t ha^{-1}. This finding is also in agreement with a report of Hue and Mai (2002) that the adequate application of lime, raising soil pH to 5.7 or higher, is essential for normal watermelon growth. Similar results were also reported by Hirpa et al. (2013) that phrenology and growth of common bean genotypes were significantly increased by the application of lime.

Tegen et al. (2021) have reported that there is a significant difference in the growth and yield characteristics of the different watermelon varieties, which also agrees with the results of this study, which showed a significant difference in fresh fruit weight (t ha^{-1}) among the watermelon varieties. Kaolack had the highest weight followed by Heracles F_1 and Sugar Baby.

Estimates of phenotypic (σ^2p), genotypic (σ^2g) and environmental (σ^2e) variances, phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), broad-sense heritability (H_b^2) and genetic advance are presented in Tables 5 and 6. The σ^2g ranged from 5.9×10^{-9} (fresh fruit yield) to 48.63 (vine length at 42 DAP), while the σ^2p ranged from 3.5×10^{-3} (rind thickness) to 332.52

(total number of seeds per fruit). GCV ranged from 1.2 × 10^{-4}% (fresh fruit yield) to 21.81% (vine length at 21 DAP). PCV ranged from 4.93% (total number of seeds per fruit) to 27.84% (fresh fruit yield). In terms of estimates for broad-sense heritability, the range was from 1.8 x 10^{-9}% (fresh fruit yield) to 90.45% (fruit length). Genetic advance (GA) ranged from 8.24 × 10^{-5} (fresh fruit yield) to 12.52 (vine length at 42 WAP). Genetic advance expressed as a percentage of the mean of the trait (GAM) ranged from 1.26 × 10^{-4}% (fresh fruit yield) to 99.44% (fresh weight per fruit). Overall, GAM was greater than GA for each of the traits except for the total number of seeds per fruit with 0.29% (GAM) and 0.93 (GA).

Table 5. The estimates of variance components and the heritability for selected growth traits in watermelons.

Estimate	Vine length (cm)				Number of leaves			
	Days after planting				Days after planting			
	21	28	35	42	21	28	35	42
Mean	9.66	19.40	35.75	58.99	4.68	7.83	10.18	17.97
Minimum	5.00	7.02	8.87	36.63	3.17	6.00	5.83	10.67
Maximum	14.98	27.37	50.53	88.90	6.33	9.17	15.67	27.50
CV (%)	29.89	25.81	28.62	23.34	16.79	12.53	25.15	25.15
σ^2_g	4.44	10.35	30.74	48.63	0.20	0.43	3.21	4.92
$\sigma^2_{r(l)}$	0.51	0.00	1.82 x 10^{-11}	0.00	0.25	0.00	0.81	0.00
σ^2_l	0.44	4.81	13.39	23.36	2.17 x 10^{-14}	0.00	0.13	2.10
σ^2_{gl}	1.31	1.39	7.77	0.00	0.04	0.39	0.42	1.13
σ^2_e	3.29	13.31	66.97	139.75	0.21	0.31	3.10	14.52
σ^2_{ph}	5.24	12.29	40.78	64.16	0.24	0.59	3.70	6.92
σ^2_g/σ^2_{ph}	0.85	0.84	0.75	0.76	0.84	0.72	0.87	0.71
$[\frac{\sigma^2_{gl}}{l}]/\sigma^2_{ph}$	0.08	0.04	0.06	0.00	0.06	0.22	0.04	0.05
$[\frac{\sigma^2_e}{lr}]/\sigma^2_{ph}$	0.07	0.12	0.18	0.24	0.10	0.06	0.09	0.23
GCV (%)	21.81	16.58	15.51	11.82	9.51	8.35	17.61	12.35
PCV (%)	23.70	18.07	17.86	13.58	10.37	9.82	18.89	14.63
H^2_b (%)	84.74	84.21	75.39	75.80	84.01	72.36	86.92	71.22
GA	4.00	6.09	9.93	12.52	0.84	1.16	3.44	3.86
GAM (%)	41.42	31.40	27.78	21.23	18.00	14.75	33.82	21.47

l = lime rate, g = genotype (variety), r = replicate, σ^2_g =, σ^2_l = genotype variance lime rate variance, σ^2_{gl} = genotype x lime rate interaction variance, $\sigma^2_{r(l)}$ = replicate within lime rate variance, σ^2_e = pooled error variance, $\sigma^2_{ph} = \sigma^2_g + \frac{\sigma^2_{gl}}{l} + \frac{\sigma^2_e}{lr}$ = phenotypic variance, GCV = genotypic coefficient of variability, PCV = phenotypic coefficient of variability, H^2_b = broad-sense heritability. GA = genetic advance at the 5% selection intensity, GAM = genetic advance as a percentage of the population mean.

Table 6. The estimates of variance components and the heritability for selected yield traits in watermelons.

Estimate	Days to 50% flowering	Number of fruits per plant	Fresh weight per fruit (kg)	Fresh fruit yield (t ha^{-1})	Fruit width (cm)	Fruit length (cm)	Rind thickness (cm)	Total number of seeds per fruit	Sugar content (Brix)
Mean	43.67	3.89	1.90	65.51	13.28	15.02	0.79	321.44	7.07
Minimum	38.00	1.00	1.05	12.00	6.65	7.15	0.45	242.00	4.50
Maximum	57.00	8.00	2.34	163.80	16.23	19.88	1.20	431.67	10.78
CV (%)	12.61	48.02	20.02	61.47	15.33	18.52	24.09	14.60	24.90
σ^2_g	2.42	0.14	5×10^{-4}	5.9×10^{-9}	0.75	5.50	8.3×10^{-4}	7.16	0.87
$\sigma^2_{r(l)}$	1.50	1.09	0.02	876.90	1.91	1.97	0.01	440.81	1.63
σ^2_l	0.00	0.16	0.00	2.6×10^{-9}	0.00	2.1×10^{-12}	9.7×10^{-9}	25.54	0.00
σ^2_{gl}	0.00	1.14	0.03	986.01	1.16	1.43	8.1×10^{-3}	731.64	0.78
σ^2_e	27.25	6.73×10^{-10}	0.00	34.68	0.93	0.93	6.7×10^{-10}	1.4×10^{-4}	0.35
σ^2_{ph}	5.44	0.52	0.01	332.52	1.24	6.08	3.5×10^{-3}	251.04	1.16
σ^2_g/σ^2_{ph}	0.44	0.27	0.04	1.8×10^{-11}	0.61	0.90	0.23	0.03	0.74
$[\frac{\sigma^2_{gl}}{l}]/\sigma^2_{ph}$	0.00	0.73	0.96	0.99	0.31	0.08	0.77	0.97	0.22
$[\frac{\sigma^2_e}{lr}]/\sigma^2_{ph}$	0.56	1.44×10^{-10}	5.7×10^{-9}	0.01	0.08	0.02	2.1×10^{-8}	6.4×10^{-8}	0.03
GCV (%)	3.56	9.61	1.34	1.2×10^{-4}	6.54	15.61	3.63	0.83	13.16
PCV (%)	5.34	18.53	6.58	27.84	8.40	16.41	7.51	4.93	15.26
H^2_b (%)	44.39	26.88	4.17	1.8×10^{-9}	60.60	90.45	23.42	2.85	74.38
GA	2.14	0.40	1.90	8.24×10^{-5}	1.39	4.60	0.75	0.93	1.67
GAM (%)	4.90	10.30	99.44	1.26×10^{-4}	10.46	30.64	95.10	0.29	23.57

l = lime rate, g = genotype (variety), r = replicate, σ^2_g = genotype variance, σ^2_l = lime rate variance, σ^2_{gl} = genotype x lime rate interaction variance, $\sigma^2_{r(l)}$ = replicate within lime rate variance, σ^2_e = pooled error variance, $\sigma^2_{ph} = \sigma^2_g + \frac{\sigma^2_{gl}}{l} + \frac{\sigma^2_e}{lr}$ = phenotypic variance, GCV = genotypic coefficient of variability, PCV = phenotypic coefficient of variability, H^2_b = broad-sense heritability, GA = genetic advance at the 5% selection intensity, GAM = genetic advance as a percentage of the population mean.

The different varieties also showed differences in the transverse section with Kaolack having a wider section and in the longitudinal section with Heracles F_1 with the longest section (Figure 2). According to Silva et al. (2018), liming resulted in higher fruit weight because calcium is the second most required element of the Crimson sweet watermelon crop. This is in line with the Kaolack variety when planted on limed soil at 5.7 t ha^{-1}. The significant interaction of liming × level factors from Silva et al. (2018) also conforms with the result here for the transverse section with Kaolack at 5.7 t ha^{-1}, which was wider than the other levels of interaction.

In the present study, the following traits had heritability values of >50%, namely, vine length, number of leaves, fruit transverse and longitudinal sections and fruit sugar content. The significant difference in performances among watermelon genotypes was due to their inherent genetic differences, phenotypic variations, and differences in soil pH levels influenced by soil amendment with agricultural lime. GCV and PCV estimates are normally categorized as low (< 10%), moderate (10–20%) and high (> 20%) as indicated by Deshmukh et al. (1992). In this study, the highest GCV and PCV values were recorded for vine length at 21 DAP (21.81%) and fresh fruit weight (27.84%). Simultaneously, moderate GCV and PCV values (i.e., where both estimates were 10–20%) were recorded for vine length (28–42 DAP), number of leaves (35–42 DAP), fruit length and Brix value. Our results are similar to those of Anburani (2018), where high PCV and moderate GCV were recorded for fruit diameter, flesh thickness, number of fruits per plant and yield per plant in thirty genotypes of watermelon of different origins. The present study showed that all PCVs were relatively higher than the corresponding GCVs. The differences between PCV and GCV indicated the level of the influence of the environment on the expression of these traits.

Figure 2. Harvested whole mature fruits of watermelon varieties.
R_0 = no lime; R_1 = 2.7 t ha^{-1} lime; R_2 = 5.6 t ha^{-1} lime; V_1 = Heracles F_1; V_2 = Kaolack; V_3 = Sugar Baby.

According to Singh (2001), estimates of heritability are classified as low (< 40%), medium (40–59%), moderately high (60–79%) and very high (≥ 80%). Low estimates of broad-sense heritability were reported for fresh weight per fruit (4.17%), number of fruits per plant (26.88%), fresh fruit yield (1.8 x 10^{-9}%), rind thickness (23.42%) and total number of seeds per fruit (2.85%). Medium heritability was reported for days to 50% flowering (44.39%), moderately high heritability estimates were recorded for vine length at 33–42 DAP (75.39–75.80%), number of leaves at 28 DAP (72.36%) and 42 DAP (71.22%), fruit width (60.60%) and Brix (74.38%). Very high heritability estimates were recorded for vine length at 21–28 DAP (84.21–84.74%), number of leaves at 21 DAP (84.01%) and 35 DAP (86.92%) and fruit length (90.45%). Traits with high heritability estimates result in an increased population response to selection in the desired direction (Acquaah, 2007).

Genetic advance is a measure of predetermined progress under an artificial selection program. According to Johnson et al. (1955), the value of GAM is categorized as low (< 10%), moderate (10–20%) and high (> 20%). In this study, a low GAM value was recorded for days to 50% flowering, fresh fruit yield, and total number of seeds per fruit, indicating that these traits are not governed by additive genes and selection for watermelon improvement is ineffective for these traits. High GAM estimates were recorded for vine length at 21–42 DAP (21.23–41.42%) and moderate to high GAM for number of leaves at 21–42 DAP (14.75–33.82%). Moderate GAM was also recorded for number of fruits per plant (10.30%), fruit width (10.46%). Fresh weight per fruit (99.44%), rind thickness (95.10%), fruit length (30.64%) and Brix (23.57%) showed high GAM estimates. The high heritability coupled with genetic advance indicates that additive gene action controls the expression of inheritance of these traits.

Overall, the estimates of heritability and GAM were moderate to high for vine length, number of leaves, fruit width (transverse section), fruit length (longitudinal section), rind thickness and Brix (sugar content). Apparently, these traits are critical to identify the potential for developing superior watermelon genotypes and/or improving the population through selection. In the present study, the marked difference in performances among watermelon genotypes was due to their inherent genetic differences and phenotypic variations, as well as differences in soil pH levels as influenced by soil amendment with agricultural lime. Heracles F_1 and Kaolack watermelon varieties outperformed Sugar Baby in terms of growth and yield traits. The application of 2.7 t ha^{-1} and 5.7 t ha^{-1} of $CaCO_3$ to the three watermelon varieties significantly influenced growth and yield traits: it effectively increased fresh fruit weight (t ha^{-1}), fruit transverse and longitudinal sections and sugar content. Heracles F_1 × 2.7 t ha^{-1}, Heracles F_1 × 5.7 t ha^{-1}, Kaolack × 2.7 t ha^{-1} and Kaolack × 5.7 t ha^{-1} showed the highest performance in both growth and yield traits.

Conclusion

The study reveals that watermelon varieties, Heracles F_1 and Kaolack, have great potential to thrive well in lime-amended acidic soils in Calabar, Cross River State. $CaCO_3$ at 2.7 t ha^{-1} and 5.7 t ha^{-1} proved suitable for watermelon production in Calabar as these rates could reduce soil acidity (pH = 4.6) by 21.74% and 43.48%, respectively. The findings of the present study highlight that watermelon production in Nigeria is no longer an exclusive agricultural enterprise of the northern states.

Acknowledgements

The authors are grateful to the Crop Improvement Unit, Department of Crop Science, University of Calabar for providing research facilities and farm workers to carry out the work. The laboratory analysis support of the Soil Science Department, University of Calabar is duly acknowledged.

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Received: January 16, 2023
Accepted: August 8, 2023

VARIRANJE RASTA, PRINOSA I KOMPONENTI PRINOSA LUBENICE (*CITRULLUS LANATUS*) UZGAJANE NA KALCIFIKOVANOM ($CaCO_3$) KISELOM ZEMLJIŠTU JUGOISTOČNE NIGERIJE

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R e z i m e

Postavljen je poljski ogled kako bi se procenio rast i prinos lubenice *Citrullus lanatus* [(Thunb.) Matsum. & Nakai] u uslovima kiselih zemljišta u Kalabaru, država Kros River, Nigerija. Ogled je bio faktorijalni 3 × 3 postavljen u okviru potpuno slučajnog blok dizajna (PSBD) sa tri ponavljanja. Faktori koji su proučavani su bile sorte (Heracles F_1, Kaolack i Sugar Baby), količine kreča (0 t ha^{-1}, 2,7 t ha^{-1} i 5,7 t ha^{-1}), i njihove interakcije na osobine rasta i prinosa lubenice. Heracles F_1 i Kaolack su nadmašili Sugar Baby ($p \leq 0{,}05$) u pogledu osobina rasta i prinosa. Količine kreča od 2,7 t ha^{-1} i 5,7 t ha^{-1} povećale su početni raspon pH zemljišta (4,6–4,9) za 21,74% (5,4–5,8) odnosno 43,48% (6,4–6,7). Ove doze su poboljšale pH zemljišta do opsega pogodnog za gajenje lubenice u oblasti istraživanja. Dužina vreže, broj listova, poprečni i uzdužni presek plodova i sadržaj šećera u plodovima imali su ≥ 50% heritabilnosti, što je koristan indeks pri odabiru osobina rasta i prinosa kod lubenice. Uopšteno uzev, GAM je bio veći od GA za svaku od osobina, osim za ukupan broj semena po plodu. Preporučuje se istraživanje na više lokacija kako bi se dobio bolji uvid u ovu pilot studiju.

Ključne reči: briks, plodovi, heritabilnost, hibrid, kreč, kiselost zemljišta, ultisol, lubenica.

Primljeno: 16. januara 2023.
Odobreno: 8. avgusta 2023.

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