Hue University Journal of Science: Agriculture and Rural Development ISSN 2588–1191
Vol. 128, No. 3B, 2019, P.17–26; DOI: 10.26459/hueuni-jard.v128i3B.4973

CORRELATIONS BETWEEN FRUIT'S YIELD WITH HORTICULTURAL TRAITS AND INHERITANCE OF MORPHOLOGICAL TRAITS OF SPONGE GOURD (*LUFFA CYLINDRICA*)

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Abstract: Enhancing the production yield fornew generations of each horticultural crop needseffective selecting programs to find outexcellent traits forming thisfruit yield. Therefore,this study aims to investigate the correlations between the fruit yield withhorticultural traits, mainly with yield's components and inheritance of some morphological traitsofsponge gourd (*Luffa cylindrica*). An F_2 population was generated from a cross between sponge gourds GBVN006904 (male) and GBVN005333 (female) at University of Agriculture and Forestry, Hue University,Vietnam. The positive correlations are observed between the fruit yield per plant andthe fruit diameter, fruit weight, and number of fruits per plant (0.901**). The male first flower appearance time showsa significant positive correlation with female first flower appearance one. The peduncle length correlates positively with the fruit length. The fruit length is enhanced when fruit weight increases. The total soluble solids and fruit diameter show a slightly negative correlation. Chi-square analysis for the leaf shape, depth of lobing, leaf color, and leaf pubescence shows a good fit to a ratio of 9:6:1, thus being controlled by duplicate genes interaction. The fruit color (dark-green:light-green) fits well to a ratio of 15:1, giving its control to duplicate genes with dark-green color being dominant, whereas the fruit shape assorts independently according toa ratio of 9:3:3:1. The fruit stripe color exhibits monogenic incomplete dominance, and the curvature of the fruit is a monogenic recessive trait. Fruit yield components, such as the number of fruit per plant, the fruit weight, and the fruit diameter,strongly affect the fruit yield of sponge gourd. The inheritance of morphological traits indicates that most of the traits are controlled by complete dominance at both gene pairs excepted for fruit strip color and curvature of fruit.

Keywords: correlation, inheritance, morphological traits, sponge gourd, yield components

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Submitted: September 04, 2018; Revised: October 02, 2018; Accepted: December 13, 2018

1 Introduction

Sponge gourd (*Luffa cylindrica*), also known as smooth loofa, bath sponge or dishcloth sponge, is locally called "muophuong" in Vietnam. Sponge gourds are widely cultivated in Africa, Brazil, the USA, and Asian countries, particularly in China, India, and Vietnam [22] due to its adaptability to subtropical and tropical regions. The young sponge gourdfruits with green skin are tender and used as an edible vegetable becausethey are tasty and easy to digest when consumed [20]. This fruit hasvarious pharmacological uses and isa beneficial element of traditional Chinese medicine [6]. The extract of sponge gourd fruitscontains various antioxidant phytonutrients (20.74 mg/g of total phenolics, 17.94 mg/g of flavonoids, 0.5 mg/g of total anthocyanins, and 1.2 mg/g of ascorbic acid) and shows over 80% inhibition on nitric oxide generation[4]. Because of their chemical properties, sponge gourds are considered as a potential resource for researchin biochemistry, environment, medicinal chemistry, and food chemistry [1, 5, 6, 11, 18, 29].

Sponge gourd is a diploid species with 26 chromosomes (*n*=13). Being a cross-pollinated crop, it harbors enormous variability in nature for the shape of leaf and fruit, color, fruit size, and fruit quality. Singh et al. suggest that the yield, being a complex factor, depends on several component characters and their interaction with the environment [32]. Developing and maintaining a genetically uniform sponge gourd variety is more complicated than that of a self-pollinated crop. Knowledge of correlations between yield and yield components in sponge gourd is essential to develop effective strategies to raise its productivity and production. Furthermore, it is necessary for reinvigorated breeding programs to have more information about the genetic nature of traits in sponge gourd. Studies related to genetic correlations and variability are numerous and reported in the literature ofridge gourd [2,8,14,23], bitter gourd [3,28],and Cucumis genus [15,19]. Inheritance is reported variously in gourd species such as analysisof gynoecismin bitter gourd [26], stem and leaf morphological traits in pointed gourd [16]and antioxidant properties and mineral content inridge gourd [13]. However, the information available on gene interaction leading to the expression of phenotypes for morphological traits in sponge gourd is very limited. In this study, the chi-square method is used as a tool to measure the 'goodness of fit' between expected and observed values to understand the inheritance of characters in segregating families. Hence, the present study aims to evaluate the correlation between everytwo traits of fruit yield and the horticultural traits.It focuses on the yield's components and inheritance of morphological traits forsponge gourd to advance theknowledge for breeding programs in the country.

2 Materials and methods

Plant material

The crosses between two varieties: GBVN006904 (B29) as male (♂) and GBVN005333 (B9) as female (♀) were carried outin 2014 to develop an F_1 generation. Varieties B29 and B9 were developed according to three cycles of self-pollination. Their seeds were provided bythe Plant Genetic Resource Center of Viet Nam. Variety B29 has an aromatic trait, which is not presentin B9. The seeds of two driedfruits resulting from self-pollination in an F_1 generation were extracted and then air-dried to produce F_2 plants. The F_2generation consisting of 86 individual plants was grown and evaluated in this study.

Sponge gourd plants were cultivated according to national technical regulations QCVN 2013 DUS of Angel Loofah (*Luffa acutangula*). The spacing is 0.6 m between plants and 1 m between rows. After the appearance of 2–3 true fully expanded leaves, sponge gourd plants were transplanted in the greenhouse field. The basal fertilizers for this experiment include 20 tons manure, 120 kg superphosphate ($Ca(H_2PO_4)_2$)and 30 kg potassium (KCl) per hectare. When the plants are 20-days old, fertilizers are adjusted and supplied to plants in the nutrient solution at a 20-day interval with 300 kg N:P:K (16:16:8), 200 kg urea, and 30kg potassium per hectare.

Methods

Experimental design: the study was conducted from September 2015 to April 2016 in a greenhouse at University of Agriculture and Forestry, Hue University. The F_2 individual plants were studied in a complete random design without replication. The observations include the appearance time of the first male and female flower on each plant, the number of fruits per plant, the fruit weight (g), the fruit diameter (cm), the fruit length (cm), the fruit yield per plant (kg/ha), the peduncle length (cm), and the total soluble solids (Brix). The leaf shape, depth of lobing, leaf color, and ventral leaf surface, fruit skin color at harvest (immature-edible fruit), fruit shape, fruit strip color and the curvature of fruitwere also observed in the study. These traits were observed on five random fruits of each plant at harvest.

Statistical analysis: the average values were calculatedusingExcel 2007. The segregation ratios were analyzed using the chi-square of Carl Pearson according to the formula: $\chi 2 = \sum[(O_i - E_i)^2/E_i]$, where $E_i$is the expected number in class i and $O_i$is the observed number in class i. The analysis of the correlation of morphological traits was carried out using SPSS, version 20.0.

3 Results and discussion

Correlation analysis between fruit yield and horticultural traits

The phenotypic correlation coefficients betweenfruit yield and its components are presented in Table 1.

Table 1. Correlations (*r*) betweenfruit yield and yield components in sponge gourd F_2 population of GBVN006904 (B29) andGBVN005333 (B9) cross

	FYP (g)	DFMA (day)	DFFA (day)	PL (cm)	FD (cm)	FL (cm)	FW (g)	TSS (°Brix)	NFP (fruit)
FYP (g)	1	0.018	0.103	–0.073	0.317**	0.036	0.521**	–0.129	0.901**
DFMA (day)		1	0.359**	–0.077	0.054	–0.012	0.149	–0.164	0.050
DFFA (day)			1	–0.076	–0.122	0.028	0.030	–0.005	–0.011
PL (cm)				1	–0.070	0.228*	0.091	0.162	–0.163
FD (cm)					1	0.055	0.534**	–0.271*	0.128
FL (cm)						1	0.240*	0.147	–0.073
FW (g)							1	–0.129	0.135
TSS (°Brix)								1	–0.134
NFP (fruit)									1

* Significant at the 0.05 level (2-tailed); ** Significant at the 0.01 level (2-tailed)

FYP = Fruit yield per plant, DFFA = Days to first female flower appearance, DFMA = Days to first male flower appearance, PL = Peduncle length, FD = Fruit diameter, FL = Fruit length, FW = Fruit weight, TSS = Total soluble solids, NFP = Number of fruits per plant.

The analysis indicates that the fruit yield per plant is highly positively correlated with the number of fruits per plant (*r*=0.901**), fruit weight (0.521**), and fruit diameter (0.317). The fruit yield is produced by yield attributing components and is a convoluted character influenced by genetic and environmental effects [21, 34]. The phenotypic coefficient variation is higher than the corresponding genotypic coefficient variation, indicating that environment plays an important role in the expression of various characters in sponge gourd [16]. The results showthat when the number of fruits per plant, fruit weight and fruit diameter increase, the fruit yield per plant also increases. The correlation between the fruit yield and the number of fruitsis consistent with that reported by Kumar et al., who report direct positive effects of the fruit weight and the number of fruits per vine to the fruit yield per vine (*r*=0.66 and 0.73, respectively) [17]. Rana et al. also report a significant positive phenotypic and genotypic correlation between the fruit yield and the total number of fruits forsnake gourd [27]. The yield per vine also hasa high significant positive correlation with the average fruit weight (0.993) forridged gourd [14]. The yield contributing components increase the yield per vine and also increase the yield per hectare, and a similar view is foundforbitter gourd [10]. An increase in the fruit diameter leads to anincrease in yield because these two parameters have a positive correlation (0.583*) [32]. In the present study, however, no significant positive correlation is observed between the fruit length and the fruit yield per plant. Previously, fruit length is considered as an important character for enhancing the yield potential [16]. Zang et al. report that both the genotype and growing environment affect the fruit length and fruit diameter [34]. The fruit yield per plant is not correlated with the time from sprouting to the appearance of the first female flower, time from sprouting to the appearance of the first male flower, peduncle length, fruit length, and Brix.

Relationships among horticultural traits

Fruit weight has a significantly positive correlation with fruit diameter (0.534**) but not with fruit length (0.240). Fruit weight increases when fruit size consisting of fruit diameter and fruit length increased. Various reports indicate high heritability (84%) of fruit length [24,25,30, 31]. Sponge gourd fruit length is one of the characters withhigh heritability and high genetic advance [21]. Other authorsreport that average fruit weight has a positive correlation with the node at which the first female flower appears (0.226) [10]. In this study,the fruit weight doesnot correlate with the number of fruits per plant, whereas Zalapaet al.report asignificant negative correlation between the fruit number per plant and average fruit weight(–0.58) formelon [33]. They announce that fruit weight per plant and average weight per fruit are mainly controlled by the dominance and epistatic genetic effects.Meanwhile, Rani et al. report that both additive and dominance genesaffectfruit weight forbitter gourd [28]. In this study, fruit length doesnot haveany close correlation with other fruit yield components.

The first female flower appearance timeis highly dependent on the first male flower appearance time(0.359, Table 1) because this time indicates the onset of the reproductive phase of the plant. However, these horticultural traits are reported to have a low genotypic coefficient of variation forbottle gourd [30]. In this study, there is asignificant negative correlation (–0.271) between the total soluble solids (TSS) and the fruit diameter, whereas the increase in TSS brings about an enhancement in the sponge gourd yield at both genotypic and phenotypic levels [17]. The peduncle length is not significantly correlated with the fruit length (0.228).

Inheritance of leaf traits

Table 2 presents segregation data for the leaf morphological traits observed in GBVN006904 × GBVN005333 F_2 population. Chi-square analysis of the morphological traits of sponge gourd is reported here for the first time. Fifty plants haveorbicular leaveswith shallow lobing, 30 plants have reniform leaves with medium lobing, and 6 plants have ovate leaveswith deep lobing. Four-ty eight plants havedark green leaves, 33 plants have green leaves, and 5 plants have light green leaves. Of 86 F_2 plants, 50 have high, 27 medium and 9 low leaf pubescence. In these progenies, high leaf pubescence is prevalent, but in another report of pointed gourd, the low leaf pubescence is more frequent than the high one [16]. In all the three cases (leaf shape and depth of lobing, leaf color, and leaf pubescence), a good fit for a ratio of 9:6:1 is obtained. Thisindicates that the control of two non-allelic genes regulates the expression of these traits. In the F_1 population, we found that the leaf shape, color, and lobingare ovate, green and medium, respectively (data not shown).

Table 2. Chi-square analysis of some leaf morphological traits in F2 populations of GBVN006904 (B29) andGBVN005333 (B9) cross in sponge gourd

	Observed value			Expected ratio	χ^2	*p* value
Shape and depth of lobing	Orbicular, shallow	Reniform, medium	Ovate, deep			
F2 (fruit #1)	39	20	4	9:6:1	0.92	$0.5<p<0.9$
F2 (fruit #2)	11	10	2	9:6:1	0.73	$0.5<p<0.9$
F2 (pooled)	50	30	6	9:6:1	0.28	$0.5<p<0.9$
Color	Dark green	Green	Light green			
F2 (fruit #1)	34	25	4	9:6:1	0.14	$0.975<p<0.995$
F2 (fruit #2)	14	8	1	9:6:1	0.27	$0.5<p<0.9$
F2 (pooled)	48	33	5	9:6:1	0.05	$0.975<p<0.995$
Leaf pubescence	High	Medium	Low			
F2 (fruit #1)	35	19	6	9:6:1	1.99	$0.1<p<0.5$
F2 (fruit #2)	15	8	3	9:6:1	2.07	$0.1<p<0.5$
F2 (pooled)	50	27	9	9:6:1	3.35	$0.1<p<0.5$

Inheritance of fruit traits

The results of chi-square analysis of the fruit morphological traits are presented in Table 3. Fruit color is an important qualitative trait, andit may have a continuously varied color spectrum from dark-green to light-green. However, in this study,only two colors: dark-green and light-green are observedat harvest. The results indicate that 79 plants have dark-green and 7light-green fruit skins. The expected ratio of the F_2 progenies givesa good fit for a 15:1 ratio for fruit skin color, indicating duplicate dominant epistasis by complete dominance at both gene pairs. Meanwhile,Eminaet al.announce that the fruit color of bottle gourd is determined by two dominant genes, resulting in F_2 population with the ratio of ninevariegated, threedark and four light fruits,indicating recessive epistasis [7]. Fruit shape is a trait built fromfruit length and fruit circumference [34]. In this study,fruit shape shows a large variation and segregates into four types in F_2:45 plants with elliptical fruits, 20 plants with elongate elliptical fruits, 14 plants with elongate slim fruits, and 7 plants with elongate blocky fruits. This segregation givesa good fit for a ratio of 9:3:3:1, indicating the control of fruit shape under two non-allelic gene interactions. The relationship among fruit shape genes of sponge gourd revealsthat the ratio is like an independent assortment. The elliptical fruits are more decorative than the other shapes. Zang et al. (2008) point out that the fruit shape of sponge gourd is determined by the maternal gene effects and they suggest that it is necessary to carefully select the parents at the first maturation stage, 3 days after flowering, to improve fruit shape traits for the gourd markets [34]. The presence of stripe on tested sponge gourd landraces in Nepal is reported, but their color is not mentioned [9]. Other studies onpointed gourd indicate two types of stripe color: green white stripe and white stripe [12]. In this F_2 population, the fruit stripe color isdetermined by a single gene (1:2:1) since 25 dark-green, 40 green and 21 light-green stripes are observed. The fruits are either straight or curved. Sixty plants have straight fruits, whereas 26 plants have curved fruits, so the results give a good fit to a 3:1 ratio. Thus, the curvature of sponge gourd fruits is a monogenic recessive trait. The F_1 generation has dark-green fruit skin, elliptical slim shape, green stripe and straight fruit (data not shown). The informationof leaf and fruit inheritance isnecessary for sponge gourd breeders to estimate the number of individuals that need to be grown or screened for desired phenotypes or genotypes.

Table 3. Chi-square analysis of some fruit morphological traits in F2 populations of BVN006904 (B29) andGBVN005333 (B9) cross in sponge gourd

	Observed value				Expected ratio	χ^2	*p* value
Skin color	Dark green	Light green					
F2 (fruit #1)	57	6			15:1	1.15	0.1<*p*<0.5
F2 (fruit #2)	22	1			15:1	0.14	0.5<*p*<0.9
F2 (pooled)	79	7			15:1	0.52	0.1<*p*<0.5
Fruit shape	Elliptical	Elongate elliptical	Elongate slim	Elongate blocky			
F2 (fruit #1)	32	15	11	5	9:3:3:1	1.25	0.5<*p*< 0.9
F2 (fruit #2)	13	5	3	2	9:3:3:1	1.92	0.5<*p*< 0.9
F2 (pooled)	45	20	14	7	9:3:3:1	1.94	0.5<*p*< 0.9
Stripe color	Dark green	Green		Light green			
F2 (fruit #1)	18	30		15	1:2:1	0.43	0.5<*p*< 0.9
F2 (fruit #2)	7	10		6	1:2:1	0.48	0.5<*p*< 0.9
F2 (pooled)	25	40		21	1:2:1	0.79	0.5<*p*< 0.9
Curvature	Straight	Curve					

	Observed value		Expected ratio	χ^2	*p* value
F2 (fruit #1)	43	20	3:1	1.53	0.1<*p*<0.5
F2 (fruit #2)	17	6	3:1	0.01	0.9<*p*<0.975
F2 (pooled)	60	26	3:1	1.26	0.1<*p*<0.5

4. Conclusions

On the basis of this study, breedersshould consider fruit traits such as the number of fruit per plant, fruit weight, and fruit diameterfor a selection of a high-yield new sponge gourd variety.The analysis of leaf traits and fruit traits shows that most values are inherited by the interaction of more than one gene except for the fruit strip color and curvature. The present study is a preliminary evaluation of the correlation between the yield and horticultural traits and the inheritance of morphological traits of sponge gourd in Vietnam. More profoundstudies on phenotypic and genetic correlations, heritability, inheritance and genetic advance are required to generate necessary and reliable knowledge for initiating an effective breeding program.

Acknowledgment

The authors are grateful to the Vietnam Ministry of Education and Training for supporting this research through Grant No. B2014-DHH123.

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