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Research Article

Variation in the Growth and Popping Indicators of Argentina-derived Popcorns in Vietnam

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Abstract

The development of popcorn genotypes that are high-yielding and with high popping abilities is fundamental to the expansion of popcorn production. In this study, a total of 23 newly developed full-sib FS3 lines of popcorn were evaluated under upland field conditions in the spring cropping season in 2021. The plant genotypes were evaluated for growth duration, plant height, number of leaves, ears/plant, ear length, ear diameter; the number of kernels, seeds per row, 1000-seeds weight, seed yield, and the proportion of floury endosperm, and popping indicator. Our results showed that the growth duration of the popcorn lines ranged from 96 - 121 days, plants were between 103.7 - 200.6 cm in height, and the number of leaves ranged between 12.92-18.13. The number of ears/plants, ear length, ear diameter, and number of kernel rows and seeds per row were 0.3-1.3, 9.6 - 20 cm, 2.3 - 4.2 cm, 7.33 -13.6 and 6.2 - 31.9, respectively. The popcorn lines were diverse in grain color and classified into white, yellow, black, pink, white yellow, and white pink. The grain yield varied from 2.13 - 64.58 quintals/ha, in which NO-11 had the highest yield of 64.58 quintals/ha. Popping indicators varied among genotypes and were negatively and positively correlated with 1000-seed weight and proportion of floury endosperm, respectively. In this study, we identified some genetic resources, such as NO-2, NO-12, NO-14, NO-20, and NO-22, which had the best popping ability. These resources will provide insights into the mechanisms of popping ability and important materials for breeding programs.

Introduction

Popcorn (*Zea mays everta* Sturt), which is a *Zea mays* species, *Zea genus*, *Poaceae* family (*Gramineae*), is a particular type of flint maize (Al et al., 2023). When the kernel is heated to a suitable temperature, it pops, and it is called "popcorn" in small form, dent (snack), and is commonly used as an ingredient for infants and adult foods (Rooney & Serna-Saldivar, 2003). Despite the high price, the demand is still enormous, and thus increasing local production of popcorn would be a more sustainable way to satisfy the market demand. To expand popcorn production, there is a need to develop popcorn genotypes that are high-yielding and have high popping ability (Soylu & Tekkanat, 2007; Effa et al., 2011; Thakur et al., 2021).

Popcorn represents one of the most popular snacks for customers in a large part of the world (Soylu & Tekkanat, 2007). popping ability is the most critical quality factor because the popped snack is usually sold by volume. Other popcorn attributes, such as tenderness and crispness, are positively correlated with popping volume. The popping ability plays an important quality standard commercially because consumers buy popcorn grains by weight and sell the popped corn by volume (Ceylan & Karababa 2002).

Among the components of seed structure, the proportion of floury endosperm strongly affects the microwave-popping performance of popcorn kernels (Pordesimo et al., 1990). Popcorn is a corn kernel that expands when heated, and for this to happen successfully and dependably, the kernel must be relatively small. This is why popcorn produces seeds that are smaller than most field corn. Seed yield is inversely proportional to popping expansion,

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corroborating the findings of several researchers who reported a negative association between grain yield and popping volume in popcorn (Dofing et al., 1991; Burak & Broccoli, 2001; Vijayabharathi et al., 2009; Jele et al., 2014; Srdić et al., 2019; Zulkadir & İdikut, 2021). When a popcorn kernel is heated, the water ordinarily bound in the floury endosperm turns into vapor and bursts the kernel (Shandera & Lee, 2000). Thus, the proportion of floury endosperm positively affects the popping performance of popcorn (Pordesimo et al., 1990; Serna-Saldivar., 2022).

In many other crops, genetic diversity studies have been conducted based on genotype (using molecular markers) and phenotypic (agro-morphological) traits and their interaction with the environment (Zafar-Pashanezhad et al., 2019; Pons et al., 2023). Similarly, in popcorn, agro-morphological studies have been conducted using various popcorn germplasm to evaluate their diversity in plant growth, yield, and quality protein characteristics (Parsons et al., 2020, Sullivan et al., 2022) Popcorn varieties with superior phenotypes and genetic structure are a good source of materials in selecting popcorn varieties and are fundamental towards establishing a popcorn breeding program (Freitas-Junior et al., 2009). In Vietnam. However, limited research has been reported on popcorn, and a variety of information is rarely available and accessible. Thus, this study aimed at assessing twenty-three inbred lines of popcorn for their growth, yield and popping ability.

Materials and Methods

Plant materials

Twenty-three popcorn inbred lines, tentatively labeled from NO-1, NO-2, NO-3, NO-4, NO-5, NO-6, N-7, NO-8, NO—9, NO-10, NO-11, NO-12, NO-13, NO-14, NO-15, NO-16, NO-17, NO-18, NO-19, NO-20, NO-21, NO-22 and NO-23, used in this study were imported from Argentina. These lines were developed by the full-sib pollination method (full-sibs are derived from crosses of parents from the base population) at the third generation (full-sib FS_3).

Experimental site and layout

This experiment was conducted at the experiment area of the Food Crops Department, Faculty of Agronomy, Vietnam National University of Agriculture (latitude 20°60'N, longitude 105°56'W, altitude ~20 m.a.s.l.). To evaluate the 23 inbred lines, they were planted sequentially in rows and each row was 2.3 m long at Spring crop season 2022. Each line was planted with three replicates. Each replicate has three rows. Seeds were sown at the spacing of 65 × 25 cm. The fertilizer doses of 150 kg N ha^{-1}, 90kg P_2O_5 ha^{-1}, and 90 kg K_2O ha^{-1} were applied. All of the P_2O_5 was applied as basal at sowing time, while the N and K_2O were split equally into three applications at sowing time, 3-4th leaf, and 8-9th leaf stages. The plants were managed in the field to full maturity.

Measurements

Agronomic traits

Agronomic traits were measured according to the standard protocols used at the International Maize and Wheat Improvement Center (CIMMYT). Time of growth stages, including germination stage, tasselling stage, silking stage, and physiological maturity stage, was recorded at least 50% or more of the plants have reached or are beyond a particular stage. The anthesis-silking interval (days) was recorded as the days to 50% days silking minus days to 50% anthesis. Stem color was recorded at silking stage. Vertically wavy leaf was recorded at the tasselling stage. Plant height (cm) was measured as the distance from ground level to the base of the tassel at the silking stage. Ear height (cm) was measured from the base of the plant to the point bearing the first ear at the maturing stage. A number of leaves was noted at the 3rd, 7th, and 10th leaf stages and finally concluded at the silking stage. Leaf area index (LAI) was calculated as the leaf area divided by the ground area, where leaf area was calculated by the length x the maximum width 0.75 x the total number of leaves. Tassel length and branching were calculated in this study. The amount of pollen was determined by the method of qualitative assessment with 3 levels (less, medium, and high level). Ear length (cm) was measured as the distance from the base of the tip of the ear and kernel, respectively. Ear diameter (cm) and kernel width (cm) were measured at the central part of the uppermost ear and kernel, respectively. Kernel color also was recorded at the tasselling stage. Stem lodging (SL) was measured as a percentage of plants that were broken below the ear. Diseases and pests were measured based on a 1-5 scale where 1 was a clean plant and 5 was a severely diseased plant. The yield components were determined after harvesting time. The number of kernel rows was recorded in the central part of the uppermost ear. The number of kernels/row was recorded as an average number of kernels/five rows of five respective ears. 1000-seed weight was determined by the electronic scale (PA214 OHAUS). Theoritical yield was calculated based on yield components.

Proportion of horny endosperm analysis

A microtome studied the anatomic cross-sections of the seeds. The samples were examined under a microscope (Olympus SZ2-ILST) fitted with an Olympus EP50 WLAN-enabled camera linked to a computer (Dell Vostro, Malaysia). The horny endosperm area was measured by using EPview software. The proportion of horny endosperm in seed cut surface area was calculated by following formula:

$$\text{Proportion of horny endosperm (\%)} = \frac{\text{area of horny endosperm } (\mu m^2)}{\text{cut surface area } (\mu m^2)} x100$$

The popping indicator

The 100 kernels of each popcorn line were popped at a"high" level in a microwave oven for 180 seconds. The experiments were replicated three times. The popping indicator was calculated by the following formula:

$$\text{Popping indicator (\%)} = \frac{\text{popped seeds}}{\text{total of tested seeds}} x100$$

Data analysis

Experimental data were statistically processed on a computer using Microsoft Excel. The t-test was used to compare average values among genotypes. Hierarchical clustering based on principal component analysis was performed by "factoextra" and "FactoMineR" packages in the R 4.1.3 software.

Results and Discussion

Agronomic traits of popcorn lines

Morphological traits

The germination stage is the first stage in the life cycle of maize, from sowing to 50% of germinating. The germination duration of the popcorn lines ranged from 4 to 8 days, with most lines germinating within 4-5 days (Table 1). However, one line (NO-18) germinated lowest (8 days). For tasseling: the earliest lines to start tasseling were NO-1 and NO-23 (52 days), and the latest line (68 days) was NO-19. In the anthesis stage of the popcorn lines, it was observed that NO-1, NO-4, and NO-23 were the three lines earliest to pollinate, recording about 55 days, while popcorn two lines NO-18 and NO-19 were the latest to attain pollination, recording 72 days. During the time from sowing to silking, NO-23 was also the earliest maturing line, which is the same day as the pollination stage, about 55 days, while the lastest to silking with 76 days is NO-19 (Table 1).

Table 1. Growth stages of popcorn lines

Growth duration (GD)	No. of days	Popcorn line
Days to emergence	Min = 4	NO-1, NO-2, NO-4, NO-5, NO-6, NO-9, NO-10, NO-13, NO-15, NO-16
	Max = 8	NO-18
Days to tasselling	Min = 52	NO-1, NO-23
	Max = 68	NO-19
Days to anthesis	Min = 55	NO-1, NO-4, NO-23
	Max = 72	NO-18, NO-19
Days to silking	Min = 55	NO-23
	Max = 76	NO-19
Anthesis-silking interval	Min = 0	NO-9, NO-10, NO-12, NO-23
	Max = 5	NO-6, NO-8, NO-17
Physiological maturity stage	Short GD: <105 days	NO-1, NO-2, NO-4,NO-8, NO-9, NO-12, NO-14, NO-16,NO-22,NO-23
	Medium GD: 105 – 120 days	NO-3, NO-5, NO-6,NO-7,NO-10, NO-11, NO-13, NO-15, NO-18, NO-19, NO-20, NO-21
	Long GD >120 days	NO-17

Furthermore, the trait anthesis to silking interval was previously used in the indirect selection of popcorn lines for drought tolerance (Kamphorst et al., 2019).The number of days between the anthesis and silking of the 23 popcorn lines varied from 0 to 5 days. Four lines, NO-9, NO-10, NO-12, and NO-23, initiated pollination at the same time of anthesis and silking, and 3 lines (NO-6, NO-8, NO-17) with time differences up to 5 days. Bbebe et al. (2021) also reported popcorn variability in anthesis and silking at 64.7 days and 68.8 days, respectively.

Tassel emergency, silking, and days to physiological maturity are important attributes that affect the yield of popcorn (Stagnati et al., 2021). High-yielding and early-maturing hybrids are typically favored in corn cultivation due to their efficient use of resources and shorter growth cycles. Early-flowering genotypes often mature more quickly and tend to be more vigorous, leading to faster growth rates. These early-flowering corn plants usually have a smaller plant size and a longer kernel-filling period, contributing to their early maturity and potentially higher yields (Troyer, 2001). The growth duration of 23 lines of popcorn ranged from

96 to 121 days, divided into 3 groups: There were 10 lines with short GD, accounting for 96 - 104 days including NO-1, NO-2, NO-4, NO-8, NO-9, NO-12, NO-14, NO-16, NO-22 and NO-23. In which, 4 lines (NO-1,12, 16 and NO-23) had the shortest GD, with 96 days. The long GD group had only one line (NO-17), with 121 days. All the remaining lines are in the medium GD group (Table 1).

Olakojo et al. 2019 used stem color as a descriptive attribute while assessing the performance of nineteen popcorn lines. In this study, we also assessed the stem color of the 23 popcorn lines, and we divided stem color into the 3 main categories (Table 2), (i) the purple stem which had two lines (NO-6, NO-21), (ii) purple-blue with 7 lines (NO-3, NO-4, NO-8, NO-9, NO-10, NO-16, anh NO-18) (accounting for 30.4%) and (iii) blue-stem which consisted of the remaining 14 lines, accounting for 60.9% (Table 2).

Table 2. Morphological characteristics of popcorn lines

Morphological characteristics	Expression	No. of lines	Line
Stem color	Purple	2	NO-6, 21
	Purple-Blue	7	NO-3, NO-4, NO-8, NO-9, NO-10, NO-16, NO-18
	Blue	14	NO-1, NO-2, NO-5, NO-7, NO-11, NO-12, NO-13, NO-14, NO-15, NO-17, NO-19, NO-20, NO-22, NO-23
Vertically wavy leaf	Low	1	NO-14
	Medium	5	NO-1, NO-9, NO-13, NO-16, NO-21
	High	17	NO-2, NO-3, NO-4, NO-5, NO-6, NO-7, NO-8, NO-10, NO-11, NO-12,NO-15, NO-17, NO-18, NO-19, NO-20, NO-22, NO-23
Plant height (cm)	Min = 103.7		NO-12
	Max = 200.6		NO-5
Ear height (cm)	Min = 40.2		NO-12
	Max = 111		NO-5
Number of leaves	Min = 12.92		NO-7
	Max = 18.13		NO-18
LAI (m^2 leaf/ m^2 area)	Min = 0.76		NO-12
	Max = 2.4		NO-1

The plant height of the 23 popcorn lines was arranged between 103.7 and 200.6 cm, with line NO-5 recording the tallest plants (200.6 cm), whereas NO-12 exhibited the shortest plants (103.7cm) (Table 2). The average length of popcorn ears was 40.2 to 111 cm, with NO-12 and NO-5 having the shortest (40.2 cm) and longest (111 cm) ears, respectively. The leaf number of the 23 popcorn lines varied from 12.92 to 18.13 leaves/plant, with NO-18 (18.13 leaves) having the most number of leaves and NO-7 (12.92 leaves) having the least number. LAI ranged from 0.76 to 2.4 m^2 leaf/ m^2 across the 23 popcorn genotypes. The NO-1 showed by far the largest LAI, with 2.4 m^2 leaf/ m^2, whereas the popcorn line NO-12 had the lowest LAI (0.76 m^2 leaf/ m^2) (Table 2).

Tassel length was identified as a very useful morphological trait for indirect selection for grain yield in popcorns under water stress (Kamphorst et al., 2020). In this study, the number of tasselling branches ranged from 5.3 – 17.1 branches per plant, with NO-12 having at least 5.3 branches and NO-17 standing at the highest position, about 17.1 branches. The minimum length of the tassel is NO-6, with only 34.1 cm, and the maximum length is NO-21 (47.9cm) (Table 3).

Table 3. Tassel morphological characteristics of popcorn lines

Tassel morphological characteristics	Value	Number	Line
Tassel length(cm)	Min = 34.1	1	NO-6
	Max = 47.9	1	NO-21
Tasseling branch (branch)	Min = 5.3	1	NO-12
	Max = 17.1	1	NO-17
Amount of pollen	Less	8	NO-2,NO-7, NO-10, NO-14, NO-16, NO-20, NO-23
	Medium	8	NO-5, NO-6, NO-8, NO-9, NO-15, NO-17, NO-18, NO-19
	High	7	Others

The amount of corn pollen evaluated by magnifying glass showed that in 23 popcorn lines in the experiment, there were 8 lines with low pollen (NO-5, NO-6, NO-8, NO-9, NO-15, NO-17, NO-18, NO-19); The rest are lines with medium to high pollen (Table 3).

Ear length and ear diameter significantly affect the expansion volume of popcorn and are thus fundamental agricultural traits to be considered when selecting popcorn genotypes for certain environments (Kamphorst et al., 2020). In this study, the subgroup result showed that there were 14 lines, accounting for 60.9% of the short type of ear length under 15cm. This is a disadvantage that affects the yield of popcorn. An average ear length of 15.59 cm was previously reported in local popcorn populations (Amaral Júnior et al. 2010). The ear diameter of popcorn lines in the experiment is quite small; none of the lines had an ear diameter that reached 5 cm. The ear diameter of NO-11 appeared to be by far the highest one at 4.2 cm, while NO-20 (2.3) had the lowest number (Table 4).

Table 4. Ear morphological characteristics of popcorn lines

Ear morphological characteristics	Value	Line
Ear length (cm)	Min = 9.6	NO-15
	Max = 20.0	NO-21
Diameter ear (cm)	Min = 2.3	NO-20
	Max = 4.2	NO-11
Kernel length (mm)	Min = 7.1	NO-7
	Max = 10	NO-21
Kernel width (mm)	Min = 4.4	NO-11
	Max = 7.2	NO-3
Kernel color	white, yellow, black, pink, white yellow and white pink	

The kernel of popcorn has color diversity: white, yellow, black, pink, white yellow and white pink. The kernel length is small, which represents the characteristics of each line. The kernel length of the popcorn line ranged from 7.1 mm (NO-7) to 10 mm (NO-21), while the kernel width ranged from 4.4 mm (NO-11) to 7.2 mm (NO-3) (Table 4).

The tolerance level of pests, disease infestation and lodging resistance of popcorn lines

Pests have 2 main species: stem borers (*Pyrausta nubilalis*) and corn borers (*Heliothis zea*), mainly pests at 1–2; the highest one can be at level 3 in some lines; NO-3, NO-5, NO-13, NO-23 (stem borer); NO-4, NO-9 (corn borer). Previous studies have screened popcorn genotypes for resistance to common pests such as fall armyworm (Oliviera et al., 2018). This study also indicated that popcorn lines were affected by southern corn leaf (*Helminthoprium maydis*) and northern corn leaf (*Helminthoprium turcicum*). Both diseases appear and impact the milk stage at levels 1-3, while some lines at level 4 are NO-15, NO-18 (southern corn leaf), and NO-14, NO-22 (northern corn leaf). Almost all popcorn lines can be sheath blight resistant (*Rhizoctonia solani*). Screening of popcorn varieties against field diseases such as maize streak, downy mildew, rust, leaf blight, and auricularia and pests such as fall armyworm, birds, and rodents (Olakojo et al. 2019). Resistance to multiple diseases in popcorn was reported to be associated with genetic and environmental interactions (Carlos et al., 2022). It is interesting to note that the logding resistance in 23 popcorn lines of this study, there were two lines (NO-17 and NO-18) where the percentage of root lodging was found to be the highest rate, with 40% and popcorn NO-17, NO-18, and NO-21 stem lodging at level 4 (Table 5). Similar studies have reported lodging resistance in certain popcorn varieties and are often affected by plant height and ear height (Cabral et al., 2015).

Yield and yield component of the popcorn lines

The 1000 seed weight is one of the four components that make up the popcorn yield. The size and weight of 1000 seeds are very typical criteria used in the determination of genetic variation in popcorn varieties and are less affected by external factors. Therefore, they are important traits used to classify varieties. In this study, number of ears recorded per plant ranged between 0.33 and 1.33. The results of assessing the number of kernel rows per ear ranged from 7.33 kernel rows/ear (NO-20) to 13.6 kernel rows/ear (NO-11), there were 3 lines under 10 kernel rows/ear (accounting for 15,8%). The amount of kernel per row varies from 6.2 seeds/row (NO-6) to 31.9 seeds/row (NO-11). The results (Table 6) showed that NO-11 was recorded to be the highest one in the weight of 1000 seeds, with 248.24 grams, whereas NO-20 was found to be the lowest one, with almost 110.41 grams. The 1000-seed weight values ranged from 158.2g to 168.5g, being significantly lower than NO-11, with almost 248.24g.

The experiment's theoretical yield of 23 lines was arranged from 2.13 to 64.58 quintal/ha. The highest theoretical yield of any popcorn line was observed to be on NO-11, with 64.58 quintal/ha. Nevertheless, a relatively low theoretical yield was recorded for NO-15, with 2.13 quintal (Table 6).

Table 5. The level of pest and disease infestation and lodging resistance of popcorn lines

Resistant ability		Value	Number of lines	Line
Pest	Stem borers	3	4	NO-3, NO-5, NO-13, NO-23
		1 – 2	19	Others
	Corn borers	3	2	NO-4, NO-9
		1 – 2	21	Others
Disease	Southern corn leaf blight (0 - 5)	4	2	NO-15, NO-18
		1 – 3	21	Others
	Northern corn leaf blight (0 – 5)	4	2	NO-14, NO-22
		1 – 3	21	Others
	Sheath blight(%) (1 - 5)	-	0	No line
Lodging resistance	Root (%)	40	2	NO-17, NO-18
		10 – 30	21	Others
	Stem (1 - 5)	3 – 4	3	NO-17, NO-18, NO-21
		1 – 2	20	Others

Table 6. Yield and yield components of popcorn lines

Line	Ears $plant^{-1}$ (ear)	Number of kernel rows	Number of seeds/row	1000-seed weight (g)	Theoretical yield (quintals/ha)
NO-1	1	11.60	28.80	178.5	36.67
NO-2	1.2	13.20	26.30	140.09	35.89
NO-3	0.5	12.40	20.40	171.02	13.30
NO-4	0.6	12.80	25.60	171.9	20.79
NO-6	0.5	11.20	6.20	189.46	4.05
NO-7	0.3	8.67	13.33	224.87	5.27
NO-8	1	12.80	20.90	143.35	23.58
NO-9	1	13.00	18.30	190.69	27.90
NO-10	1	10.40	30.20	247.85	47.87
NO-11	1.3	10.20	31.90	248.24	64.58
NO-12	1	11.40	25.70	162.4	29.26
NO-13	0.6	12.00	15.83	161.53	11.32
NO-14	1	13.60	27.60	146.5	33.84
NO-15	0.3	8.00	8.67	166.3	2.13
NO-16	0.7	10.86	24.86	167.28	19.43
NO-20	0.4	7.33	12.67	110.71	2.53
NO-21	0.3	10.67	28.67	247.94	13.99
NO-22	1	13.00	25.40	145.87	29.62
NO-23	1.1	12.00	28.20	228.6	52.33

Popping indicator

Oz and Kapar (2011) also reported a significant difference in popping volume among popcorn genotypes evaluated for three years, which is similar to the results obtained in this study in Figure 1. The highest popping indicator was observef in NO-2, NO-12, NO-14, NO-20 and NO-22; while the lowest one was found in NO-07, NO-10, NO-11, NO-21 and NO-23.

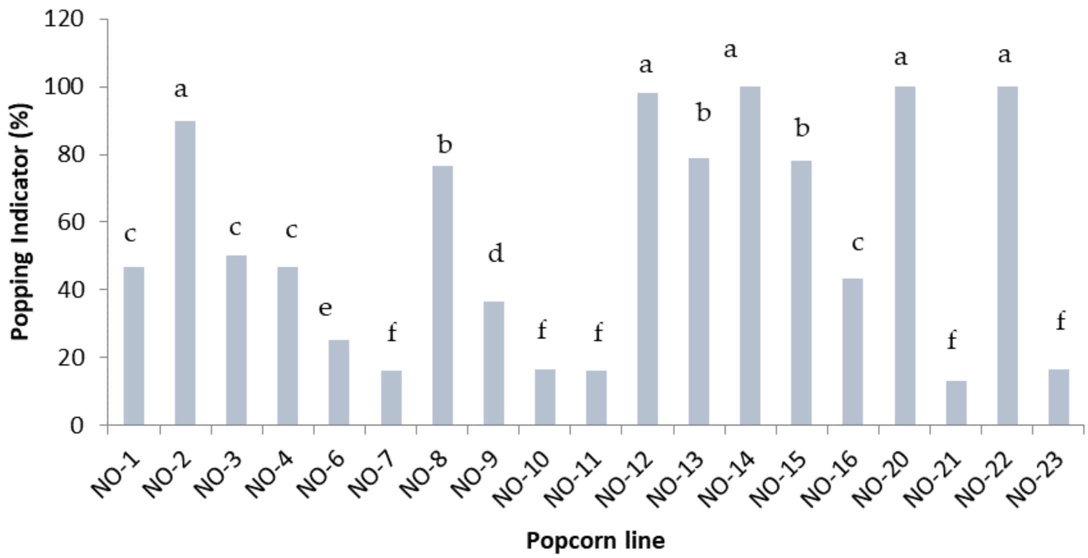

Figure 1. Popping indicators of popcorn lines at " High" level in Microwave after 180 seconds. The genotype with different letters are significantly different at *p< 0.05*.

Proportion of floury endosperm of popcorn lines

The variation in the cross-section of selected popcorn genotypes showed in Figure 2. Among the components of seed structure, the proportion of four endosperm strongly affected the microwave popping performances of popcorn kernels (Pordesimo et al. 1990). Thus, in this study, we focussed on the measurement of floury traits. The results for this trait were found to be statistically different by cultivars (Figure 3).

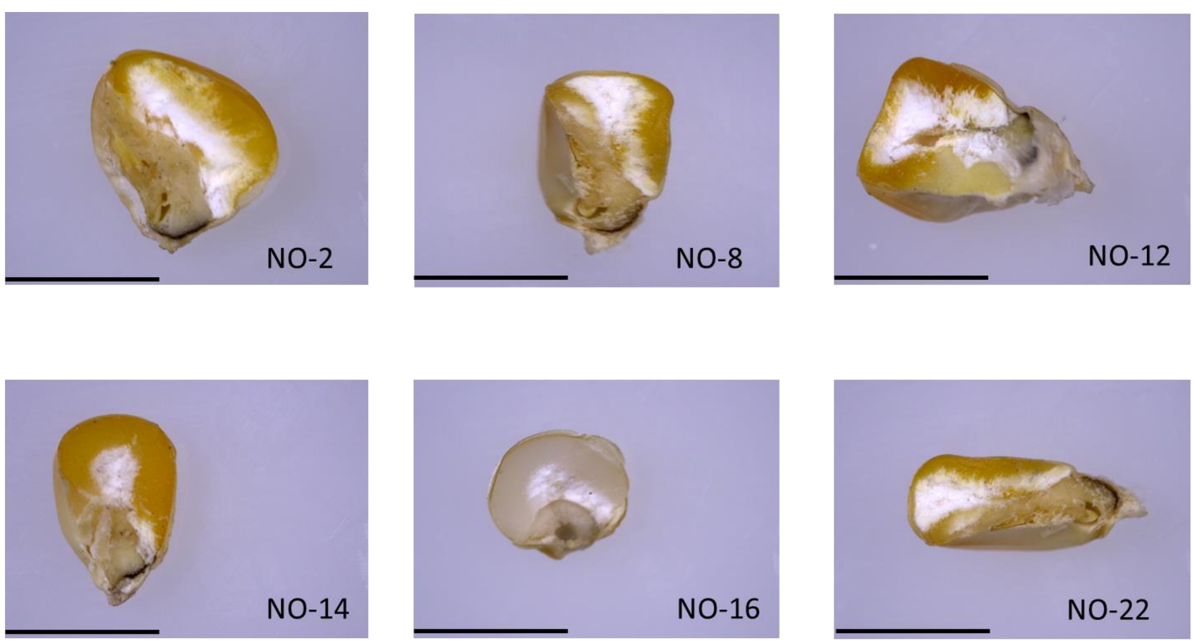

Figure 2. Seed cross-sections of popcorn lines. *Bars* 0.4cm

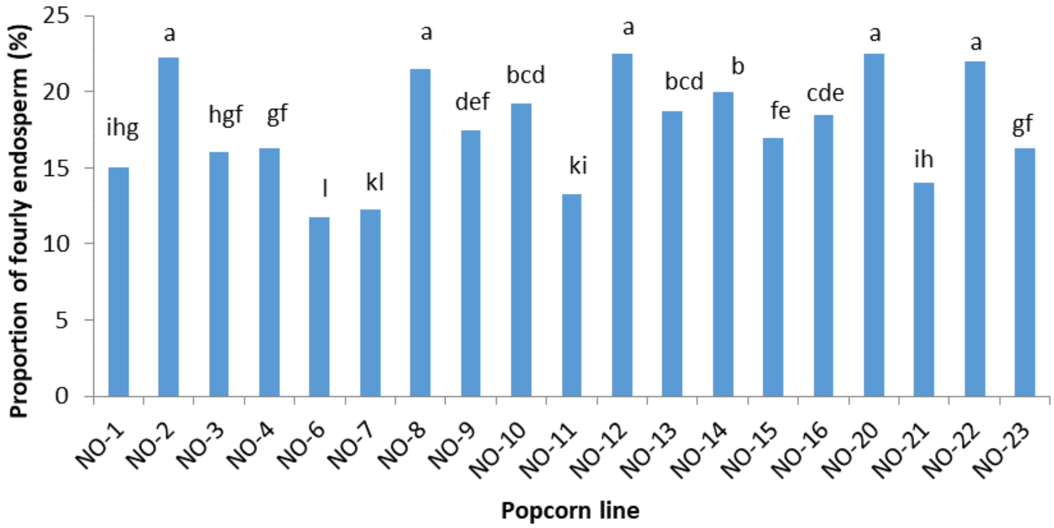

Figure 3. Proportion of floury endosperm of popcorn lines. The genotypes with different letters are significantly different at $p< 0.05$.

Relationship of popping indication with 1000-seeds weight and proportion of floury endosperm

The study found a strongly negative correlation (r = -0.72) between the popping indicator and the weight of 1000 seeds (Figure 4), indicating that seed yield is inversely proportional to popping expansion. This finding is consistent with research from several authors who reported a negative association between grain yield and popping volume in popcorn (Dofing et al., 1991; Burak & Broccoli, 2001; Vijayabharathi et al., 2009; Jele et al., 2014; Olakojo et al. 2019).

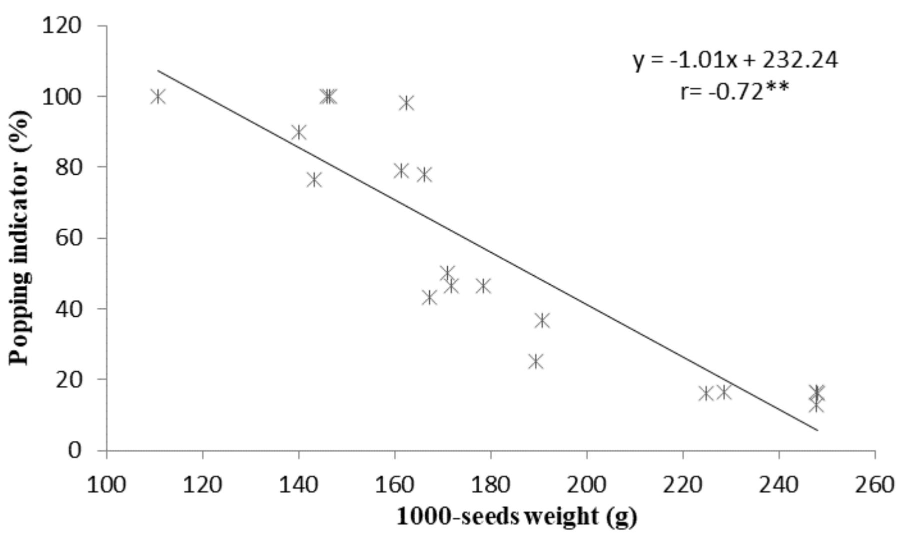

Figure 4. The relationship between 1000-seed weight and popping indicator of popcorn lines. The r with ** is the correlation coefficient at $p< 0.01$.

When a popcorn kernel is heated, the water ordinarily bound in the floury endosperm becomes vapor and bursts (Shandera & Lee, 2000). In this study, we found a positive correlation between popping indicators and the proportion of floury endosperm in popcorn lines (r = 0.82, Figure 5), indicating that the proportion of floury endosperm positively affects the popping performance of popcorn. This finding is consistent with previous research by Pordesimo et al. (1990).

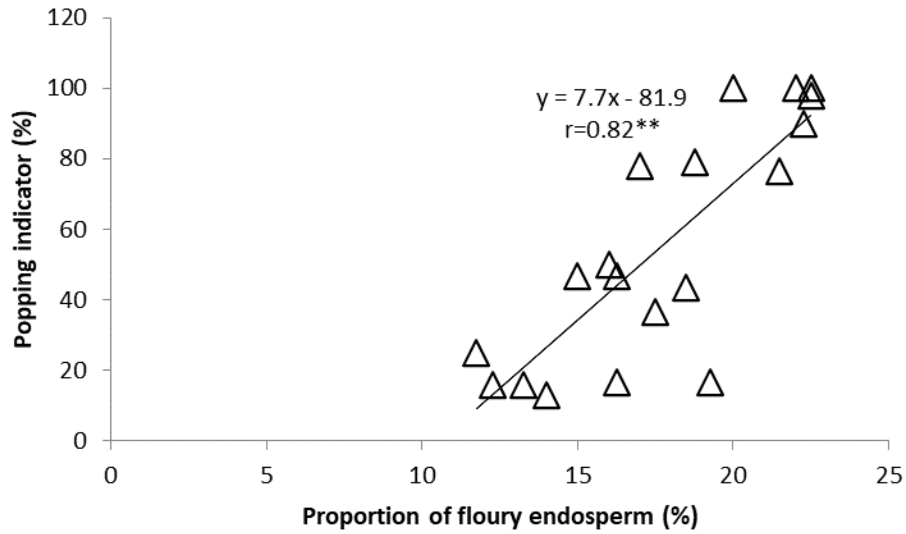

Figure 5. The relationship between the proportion of floury endosperm and popping indicator of popcorn lines. The *r* with ** is the coefficient at *p< 0.01*.

Grouping of popcorn lines by Principal component analysis (PCA)

Principal component analysis (PCA) can be used to reduce the dimensions of the data to some continuous variables that contain the most important information in the data (Ringnér 2008). In this study, we used hierarchical clustering on the principal components approach, which combines three standard methods such as PCA, hierarchical clustering, and k-means algorithm, to get a better cluster solution. Recently, have been many studies using many studies using PCA to classify traits and identify genetic diversity in common corn (Zeng et al., 2013; Dar et al., 2018; Mengistu, 2021). There are no studies on popcorn yet. Hierarchical clustering based on principal component analysis of popcorn genotypes on all measured traits showed four major clusters presented high genetic diversity of popcorn genotypes (Figure 6). The first cluster included NO-2, NO-8, NO-12, NO-14, NO-16, and NO-22. The second cluster included NO-1, NO-10, NO-11, and NO-23. The third cluster included NO-3, NO-4, NO-6, NO-7, NO-9, NO-13, NO-15, NO-20. NO-21. The fourth cluster included NO-5, NO-17, NO18, NO-19. The results of this study provided a good source of material for the popcorn breeding program and can be used to conduct further research at the morphological and molecular level on the mechanism involved in the popping ability in popcorn.

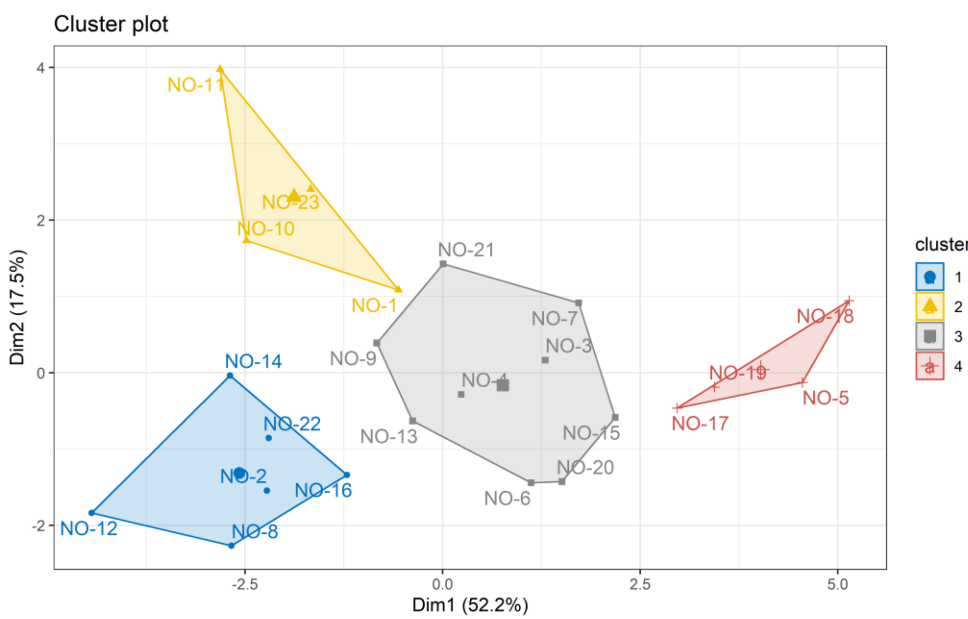

Figure 6. Hierarchical clustering based on principal component analysis of popcorn genotypes on measured traits

Conclusion

Identifying supergenotypes is fundamental for the establishment of popcorn breeding programs. A total of 23 full-sib FS3 popcorn lines were evaluated under field conditions for their growth, tolerance to abiotic and biotic stress, yield and yield components, and popping characteristics. The popcorn lines exhibited differences in their growth duration, morphological features, and grain color. The grain yield and popping ability also varied amongst the popcorn lines. Popcorn lines with better popping abilities were identified. Germplasm screening provided in this study is critical to the future breeding of new popcorn varieties that are well-adapted in Vietnam. Further research should consider identifying genes and mechanisms underlying the phenotypic differences in the identified popcorn lines.

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