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Identification of Morpho-Physiological and Yield Traits of Sweet Corn Hybrids at Various Shade Levels

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Abstract

The selection of shade-tolerant sweet corn under intercropping conditions is necessary to provide adaptive superior cultivars for agroforestry systems. Until recently, there have not been many reports of superior varieties of sweet corn tolerant to low light. This study aimed to determine the differences in the morphological, physiological and production responses of 25 hybrid sweet corn genotypes to low light intensity. This study used a nested design with three replications. The factors tested were the shade level (0%, 25%, 50% and 75%) and the genotype of hybrid corn. The results showed that most of the hybrid corn genotypes tested showed an increase in production at 25% shade, while at 50% and 75% shade, they showed a decrease in production. Based on relative production at 25% shade, the genotypes can be split into three groups: sensitive, moderate and tolerant. The tolerant genotype including F1 T8-2A x SM12-2 (G6); Exotic (G13); Talenta (G15); Golden boy (G16); F1 SM12-2 x T9-2 (G20) provided the highest increase in morpho-physiological characters and yields compared to the moderate and sensitive. In all genotype groups, morphological variables (number of leaves, leaf area, stem diameter and relative growth rate), physiological variables (stomata conductance, photosynthetic rate, and total dissolved solids (TDS)), and yield variables (length, diameter, number, weight and unhusked weight of ears) were significantly higher in the no-shade than in the shaded conditions. These findings can be used as a basis for sweet corn planting recommendations under shade condition areas such as in agroforestry systems.

Keywords: light; photosynthesis; shade tolerance; *Zea mays saccharata* Sturt

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INTRODUCTION

Sweet corn (*Zea mays saccharata* Sturt) is the main crop widely cultivated as a vegetable and industrial raw material. It is a C4 plant group with high photosynthetic efficiency and sensitivity to low light intensity (Bellasio and Griffiths, 2014). Sweet corn is most widely cultivated by households (more than 75%) (Statistics Indonesia, 2021). Increased market demand for sweet corn resulted in imports from other countries. The percentage of sweet corn productivity in Indonesia increased by 3.17% until 2015 at 5.18 tons ha^{-1}. However, these conditions demand that imports continue (Sofyan et al., 2019). The problem faced is the more serious difficulty level of agricultural cultivation caused by converting agricultural land to non-agriculture. The profitability of agricultural land is that the land is very easy to convert into non-agricultural land (Rondhi et al., 2018). This trend occurs almost every year (Prayitno et al., 2021). The effectiveness of cultivation systems using land under tree canopy (agroforestry)

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and intercropping systems can be used as an alternative approach to addressing these challenges.

Agroforestry is an integrated agricultural system that involves growing grain crops under the canopy of trees in the same area (Borges et al., 2022). The agroforestry system in sweet corn cultivation faces the problem of low light intensity due to shading. Cultivating plants with low light intensity that focuses on community productivity is multiple planting or intercropping. Intercropping cultivation can be done using an agroforestry system and utilizing forest areas (Smethurst et al., 2017). Land management with an agroforestry system can combine forestry and plantation practices to develop hybrid corn cultivation in one land area. Corn plants often experience low light stress or shade under climatic and environmental conditions (Gao et al., 2018). According to Ren et al. (2022), the combination of waterlogging and shading treatments on corn plants accelerates leaf aging, disrupts photosynthetic characteristics, inhibits the accumulation of assimilation and can reduce maize yields in summer. Previous studies have shown that low light or shade intensity can affect plant growth and development, reducing yield and quality of maize (Li et al., 2010; Gao et al., 2017). Inadequate light intensity in the cultivation system can disrupt plant metabolism and decrease plant productivity. A shade above 50% can reduce the number and weight of tomatoes that are not marketable and reduce chili yields (Masabni et al., 2016). The higher the level of shade is, the greater the decrease in brown rice production will be (Muhidin et al., 2018). Sweet corn stressed under shade conditions causes a decrease in the photoreceptor system as a plant response in increasing its ability for lightning. Gene expression (i.e., ZmphyA1, ZmphyA2, ZmphyB1 and ZmphyB2) directly responds to dynamic changes in environmental light (Shi et al., 2019).

Several agroforestry tree species, such as *Tithonia diversifolia*, *Senna spectabilis*, *Sesbania sesban* and *Calliandra calothyrsus*, have been proven beneficial for soil nutrition and increasing corn production in Eastern and Western Kenya (Palm et al., 2001; Simiyu et al., 2021). A previous study reported variations in physiology and yield among maize plants with different levels of shading (Liang et al., 2020). Previous research has documented the viability of intercropping with perennial crops such as sugarcane (*Saccharum* spp.), wheat (*Triticum aestivum* Linn.) and maize (*Zea mays* L.), which have C4 metabolism, and found differences in morphological, agronomic and physiological characteristics (Artru et al., 2017; Schwerz et al., 2018; Caron et al., 2019; Nardini et al., 2019). However, in Indonesia, a tropical country, no studies have identified shade tolerance levels in hybrid sweet corn. Selecting shade-tolerant sweet corn under agroforestry conditions is necessary to provide adaptive, superior cultivars for agroforestry systems. The identification of shade-tolerant sweet corn varieties supports sustainable agricultural systems. Assembly of high yielding shade tolerant hybrid maize is the right strategy to increase national maize productivity and production using land under tree canopy or agroforestry (Bidhari et al., 2021). Therefore, this research highlights the need for environment-related selection for shade tolerance to ensure effective and efficient production of sweet corn varieties. This study aims to determine the differences in 25 hybrid sweet corn genotypes' morphological and physiological responses and their production when grown in low-light conditions.

MATERIALS AND METHOD

Genetic materials and field conditions

The genetic materials used were 25 sweet corn hybrid genotypes from the Plant Breeding Laboratory, Department of Agronomy and Horticulture, IPB University. The field research was conducted between July and November 2022 at the Pasir Kuda experimental field (106°47'3.26" E and 6°36'31.7" S) at IPB University. Laboratory-scale analysis was conducted at the Microtechnical Laboratory and the Postharvest Laboratory, Department of Agronomy and Horticulture, IPB University. This study used a nested design with three replications. The factors tested were the shade level (0%, 25%, 50% and 75%) and the genotype of hybrid corn (Table 1).

The shading treatments were carried out using a paranet (shading densities: 25%, 50% and 75%) approximately 3 m high using a bamboo frame. Installation was done two weeks before transplanting. Hybrid sweet corn was planted with a spacing of 80 cm x 20 cm and a plot area of 12 m x 27 m for each shade category. The planting was done directly with one seed per hole with a shovel at 3 to 5 cm depth. Maintenance of the hybrid sweet corn was carried out by watering regularly, weeding was done manually using hands and replanting was done one week after

Table 1. List of sweet corn genotypes

Genotype code	♀	♂	Owner agency
G1	T10-3	SM12-2	Hybrid lines (Breeding Laboratory, IPB University)
G2	SM6-3	SM12-2	Hybrid lines (Breeding Laboratory, IPB University)
G3	SB5-1C	SM12-2	Hybrid lines (Breeding Laboratory, IPB University)
G4	T9-2	SM12-2	Hybrid lines (Breeding Laboratory, IPB University)
G5	SM10-1	SM12-2	Hybrid lines (Breeding Laboratory, IPB University)
G6	T8-2A	SM12-2	Hybrid lines (Breeding Laboratory, IPB University)
G7	SB12-2	SM12-2	Hybrid lines (Breeding Laboratory, IPB University)
G8	SB9-2	SM12-2	Hybrid lines (Breeding Laboratory, IPB University)
G9	SM7-3	SM12-2	Hybrid lines (Breeding Laboratory, IPB University)
G10	T8-2B	SM12-2	Hybrid lines (Breeding Laboratory, IPB University)
G11	SM7-8	SM12-2	Hybrid lines (Breeding Laboratory, IPB University)
G12	SM11-6	SM12-2	Hybrid lines (Breeding Laboratory, IPB University)
G13 (Eksotic)	Sy1/RK1:14-1-1-9-5-1-5-1-1-bk	SF2/BS1:1-2-1-2-4-5-3-1-1-bk	Hybrid commercial variety (Agri Makmur Pertiwi Company)
G14 (Paragon)	JMP 07 F	JMP 07 M	Hybrid commercial variety (Agri Makmur Pertiwi Company)
G15 (Talenta)	Suw2/SF1:2-1-2-1-5-3-2-1-1-bk	Pcf5/HB6:4-4-1-2-3-3-2-1-bk	Hybrid commercial variety (Agri Makmur Pertiwi Company)
G16	Golden Boy	Golden Boy	Hybrid commercial variety (Bisi International, Tbk Company)
G17	SM12-2	T10-3	Hybrid lines (Breeding Laboratory, IPB University)
G18	SM12-2	SM6-3	Hybrid lines (Breeding Laboratory, IPB University)
G19	SM12-2	SB5-1C	Hybrid lines (Breeding Laboratory, IPB University)
G20	SM12-2	T9-2	Hybrid lines (Breeding Laboratory, IPB University)
G21	SM12-2	T8-2A	Hybrid lines (Breeding Laboratory, IPB University)
G22	SM12-2	SB9-2	Hybrid lines (Breeding Laboratory, IPB University)
G23	SM12-2	SM7-3	Hybrid lines (Breeding Laboratory, IPB University)
G24	SM12-2	T8-2B	Hybrid lines (Breeding Laboratory, IPB University)
G25	SM12-2	SM11-6	Hybrid lines (Breeding Laboratory, IPB University)

planting, along with fertilizing and controlling pests and diseases. The fertilizers used were 10 tons ha^{-1} manure, 300 kg ha^{-1} NPK, 2 tons ha^{-1} dolomites and 150 kg ha^{-1} urea given 30 days after planting (DAP) (Syukur and Rifianto, 2013).

Measurement of characteristics

The characteristics observed in this study were separated into three, namely: morphological, physiological and yield-quality traits. The morphological characteristics included: plant height (cm), number of leaves, leaf area, stem diameter (mm), tasseling date and silking date. Observations were made when the plant released tassels (male and female flowers) by 50% for each genotype and relative growth rate was measured at 27 and 40 DAP. The physiological characteristics of chlorophyll a, b, carotenoids, anthocyanins, total chlorophyll and chlorophyll a/b ratio pigment content were analyzed (Sims and Gamon, 2002). Photosynthetic rate, stomatal conductance and intercellular CO_2 weight using LiCor-6400 XT portable photosynthesis system USA. Measurements were made using a third leaf sample from a fully opened shoot on a plant eight weeks after planting from 9:00 to 12:00 GMT+7. (Fan et al., 2019; Khalid et al., 2019; Mereb et al., 2020). These included measurements of stomatal density, trichomes and total dissolved solids (TDS). The yield quality characteristics were ears length and diameter, number of ears per plant, ears weight with husks and ears unhusked.

Data analysis

Collected data were analyzed statistically according to one way analysis of variance (ANOVA) technique. If the treatment gave statistically significant effect ($p < 0.05$), the different sources of variation were compared using Tukey's honestly significant difference (HSD) with SAS on demand and orthogonal contrast analysis with R Studio v. 9.0. The grouping of plant tolerance levels was determined based on previous research (Siahaan et al., 2022), using the percentage of relative plant production. Sweet hybrid corn genotypes were grouped according to the criteria: a) sensitive genotype: relative production was 60%; b) moderate genotype: relative production was between 60% and 80%; c) tolerant genotype: relative production was between 80% and 100%; and d) shade-loving genotypes: relative production was > 100%.

RESULTS AND DISCUSSION

The microclimate under the paranet shade included: a light intensity ranging from 92,650 to 17,567 Lux and temperatures ranging from 27.77 to 32.08 °C, while relative humidity ranges from 83.24 to 85.54% (Table 2). The percentage difference in shading results in reduced light intensity and temperature while relative humidity increases. The plants received varied light intensity, affecting the availability of light for conversion into chemical energy. Yuan et al. (2022) reported that 50% shade reduced light intensity and temperature but increased relative humidity in maize cultivation. Planting under shade affected maize growth because light energy converted into chemical energy used for photosynthesis was reduced and this would reduce dry matter accumulation.

Sweet corn yield was reduced by photosynthesis rate, which is the higher shade level makes lower light intensity. It requires at least eight hours of sunlight daily, an air temperature of 20 to 33 °C and humidity of 80%. Sweet corn can adapt to a wide range of climatic conditions with an altitude range of 300 m above sea level (Syukur and Rifianto, 2013). According to Salinas et al. (2022), climatic variables are crucial for plants' development and physiological processes, especially for C4 plants like corn, which require high levels of solar radiation for photosynthesis.

The correlation between shading and average grain weight per plant forms a linear curve with the equation Y = -210.62x + 196.36 (R^2 = 0.6029). As the shading level increases, grain weight production decreases until reaching the lowest point at 75% shading (Figure 1). It indicates that production decreases with increasing shading and reaches its lowest point at 75%; after that, shading decreases sweet corn production. Shading influences the yield of the sweet corn genotype used: the lower the received light intensity, the lower the harvest yield. Previous studies reported that low light intensity or shading significantly affects the growth and development of plants, resulting in decreased yield and plant quality (Hu et al., 2015). The response to the decrease in average ears production at shading levels is due to the unfilled corn kernels and small ear diameter. Ears were not filled because the tasseling age differed and the male flowers were anthesis before the female flowers emerged. Previous research has shown that lower light intensity or artificial shading greatly affects plant

Table 2. Means of microclimate in four shade levels

Variable	Shade level			
	0%	25%	50%	75%
Light intensity (Lux)	92,650	73,762	52,343	17,567
Daily temperature (°C)	32.08	31.28	29.79	27.77
Moisture (%)	83.24	83.75	84.97	85.54

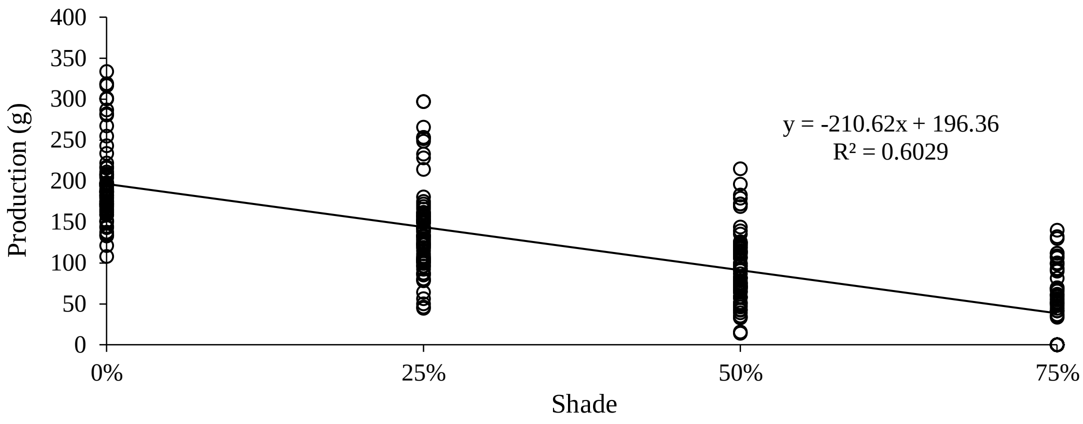

Figure 1. Ear unhusked weight response of 25 genotypes to shading

growth, reduced N accumulation, dry matter, grain yield and maize quality (Gao et al., 2020). According to Waqas et al. (2019), different shading conditions mostly affect photosynthesis and sugar translocation in plants, thereby reducing kernel filling and maize production.

The results showed that the ear weights of the 25 genotypes varied greatly (132.67 to 317.00 g) in a shade-free environment. The range of ear unhusked weight in 25% shade was 76.33 to 267.67 g, and it was more diverse than 50% and 75% shade (Table 3).

A wide range in 25% shade level makes it easier to classify genotype levels as tolerant (5), moderate (17) and sensitive (3). Therefore, the 25% shade level is the basis for determining the tolerance of sweet corn hybrids. Baharuddin et al. (2014) and Siahaan et al. (2022) showed that 50% shade level was suitable for classifying tolerant genotypes. This is because tomato and chili plants belong to the C3 group, which requires not full light intensity for photosynthesis, but it is different from sweet corn, which is a C4 plant that requires full light. According to Bellasio and Griffiths (2014), corn is a typical C4 plant, requiring high photosynthetic efficiency and optimal sunlight conditions. Still, it can limit its growth and productivity in a shady or limited light environment.

The growth characteristics are presented in Table 4. Shade and genotype sources significantly affected leaf number, leaf area, stem diameter, tasseling age, silking age and relative growth rate. At the same time, plant height was non-significant different without shade. The tolerant genotype showed that the highest average plant height was 177.90 cm at 25% shade compared to the average plant height of the moderate genotype group of 150.09 cm and 147.91 cm for the sensitive genotype. This difference in plant height was due to differences in the proportion of shade associated with the cell elongation process. Under low light intensity, plants experience changes in their morphology to maximize the use

Table 3. Production of ears unhusked weight per plant (g) with several shade intensities of sweet corn genotypes

Genotype code	Shade level			
	0%	25%	50%	75%
G1	228.33^{b-e}	145.67^{bc} (64)	102.33^{a-e} (45)	57.89^{a} (25)
G2	179.33^{def}	133.33^{bc} (74)	93.67^{a-e} (52)	37.33^{a} (21)
G3	206.00^{c-f}	141.75^{bc} (69)	96.33^{a-e} (47)	43.33^{a} (21)
G4	162.67^{ef}	99.00^{bc} (61)	58.13^{e} (36)	23.33^{a} (14)
G5	175.67^{def}	116.60^{bc} (66)	70.67^{cde} (40)	59.72^{a} (34)
G6	142.67^{ef}	122.67^{bc} (86)	73.33^{b-e} (51)	30.56^{a} (21)
G7	153.00^{ef}	76.33^{c} (50)	64.67^{de} (42)	36.53^{a} (24)
G8	132.67^{f}	81.33^{c} (61)	39.33^{e} (30)	28.89^{a} (22)
G9	191.67^{def}	150.67^{bc} (79)	94.00^{a-e} (49)	27.00^{a} (14)
G10	183.33^{def}	115.92^{bc} (63)	88.33^{a-e} (48)	33.33^{a} (18)
G11	216.67^{b-f}	141.25^{bc} (65)	90.67^{a-e} (42)	32.78^{a} (15)
G12	197.33^{def}	150.67^{bc} (76)	101.33^{a-e} (51)	0.00^{a} (0)
G13	317.00^{a}	267.67^{a} (84)	161.67^{ab} (51)	83.00^{a} (26)
G14	289.67^{abc}	179.33^{ab} (62)	151.40^{a-d} (52)	57.27^{a} (20)
G15	252.00^{a-d}	244.00^{a} (97)	174.33^{a} (69)	83.17^{a} (33)
G16	300.83^{ab}	259.73^{a} (86)	154.00^{abc} (51)	45.22^{a} (15)
G17	188.00^{def}	139.00^{bc} (74)	95.67^{a-e} (51)	22.00^{a} (12)
G18	186.00^{def}	113.33^{bc} (61)	73.00^{cde} (39)	37.08^{a} (20)
G19	187.33^{def}	115.90^{bc} (62)	75.67^{b-e} (40)	44.89^{a} (24)
G20	147.00^{ef}	122.33^{bc} (83)	69.00^{cde} (47)	37.00^{a} (25)
G21	190.00^{def}	86.67^{c} (46)	78.40^{b-e} (41)	55.42^{a} (29)
G22	149.33^{ef}	94.33^{bc} (63)	62.33^{e} (42)	11.67^{a} (8)
G23	201.67^{c-f}	150.00^{bc} (74)	82.67^{b-e} (41)	0.00^{a} (0)
G24	194.67^{def}	105.33^{bc} (54)	62.00^{e} (32)	58.75^{a} (30)
G25	189.60^{def}	138.00^{bc} (73)	107.33^{a-e} (57)	18.33^{a} (10)

Note: Means followed by the same letter in the same column in the tolerance level group are not significantly different according to the HSD test at 5%. Numbers in parentheses indicate percentages relative to controls of light (Khalid et al., 2019). The tree canopy effect significantly reduces corn plants below *Grevillea robusta* and *Eucalyptus* spp. (Nyaga et al., 2017).

The tolerant group had higher leaf numbers and larger leaf areas than the moderate and sensitive groups (Table 4). Each genotype has a different number of leaves, depending on the different characteristics and adaptability of the plant to the surrounding environment. In shaded environments, hybrid sweet corn plants reduce their number of leaves to compensate for the limited amount of light they receive. Under-light deficit conditions, hybrid sweet corn plants in the tolerant group adapted better than the sensitive group. Leaf area at 25% shade decreased more in the sensitive group (30%) than in the moderate (18.96%) and tolerant (17.80%) groups. The increase in leaf area was also determined by the carbohydrates allocated to the leaves, and shade can reduce the carbohydrates formed and leaf area. According to Chukwudi et al. (2021), heat stress in tolerant maize plants causes a reduction in leaf area and number of leaves, interfering with the plant's ability to convert light energy into biomass, which is needed for the growth of the maximum value of leaf area index (LAI max). Deficiency of water and more shade resulted in delays in plant development, and significant reductions in LAI, total dry matter and grain yield were observed under stress conditions (Ramos-Fuentes et al., 2023). Stem diameter of shade 25% had no significant effect on the tolerant group; however, it significantly affected the moderate and sensitive groups compared to no shade (Table 4). Sensitive genotypes have thin and small stems because they cannot adapt to low light-intensity stress. Under shaded conditions, corn plants produce tall and thin stems and can reduce their number of leaves (Araki et al., 2014). According to Salinas et al. (2022), the maize planted had particularities in morpho-agronomic characteristics in each agroforestry system. In general, plant height and stem diameter did not show significant differences between maize grown with myroxylon, coffee and monoculture. Planting arrangements and plant characteristics of corn are determined by various environmental conditions.

At 25% shade, the average age of tasseling and silking in the tolerant group was faster (50.88 and 53.13 days) than moderate group (50.94 and 53.86 days) and sensitive group (52 and 54.89 days) (Table 4). The 25% shade accelerated tasseling and silking age in the tolerant group compared to the sensitive genotype group. It has previously been shown that shade-adapted tomato plants flowered faster under shaded conditions than the sensitive group (Sulistyowati et al., 2016). Shading stress reduces leaf area, chlorophyll content, and photosynthetic rate, increases anthesis-silking, and reduces pollen and filament vitality, leading to decreased yield (Cui et al., 2015). The relative growth rate was observed at the age of 27 and 40 DAP by destructively weighing the dry weight of roots, stems and leaves at a temperature of 80 °C for 2 x 24 hours. The tolerant genotype had the highest growth rate compared to the moderate and sensitive groups. At 25% shade, the tolerant and sensitive genotype groups were not significantly different from those without shade, but the moderate genotypes were significantly different (Table 4). Shade resulted in a relatively lower growth rate compared to no shade, and shade reduced the relative growth rate of moderate genotypes by 4.83% compared to no shade. The relative growth rate is influenced by the ability of plants to capture photosynthetic active radiation (PAR) for the accumulation of

Table 4. Plant growth characteristics of 25 sweet corn genotypes under no-shade and 25% shade conditions

Characteristic	Tolerant		Moderate		Sensitive	
	0%	25%	0%	25%	0%	25%
Plant height (cm)	179.12^a	177.90^a	149.27^a	150.09^a	146.21^a	147.91^a
Number of leaves	10.69^a	10.17^b	9.57^a	9.22^b	9.60^a	8.82^b
Leaf area (cm^2)	527.61^a	433.67^b	435.84^a	353.19^a	397.30^a	275.26^b
Stem diameter (cm)	2.17^a	2.03^a	2.06^a	1.93^b	2.05^a	1.69^b
Tasseling age (days)	50.33^a	50.80^a	50.08^b	50.94^a	50.33^b	52.00^a
Silking age (days)	53.13^a	53.67^a	52.82^b	53.86^a	52.89^b	54.89^a
Relative growth rate (g day^{-1})	3.42^a	3.24^a	3.25^a	3.10^b	3.06^a	2.93^a

Note: Means followed by the same letter in the row and in the same genotype group were not significantly different based on the contrast test (α = 5%)

dry matter, meaning that when plants received more light, they had a greater relative growth rate (Addo-Quaye et al., 2011).

Photosynthetic pigments can be used as indicators of plants' tolerance to low light intensity. As shown in Table 5, shade level and genotype did not significantly affect the content of leaf pigments (chlorophyll a, b, anthocyanins, carotenoids, total chlorophyll and chlorophyll a/b ratio). Although, based on the contrast test, it was not significantly different in all genotype groups. However, in the tolerant genotype group, the highest chlorophyll a and b content increased by 4.4% and 8.47%, respectively. In 25% shade, the increase in chlorophyll b was higher than the increase in chlorophyll a sweet corn genotype. Its increase in chlorophyll b would increase the efficiency of light capture. The ratio of chlorophyll a/b in the sensitive genotype group experienced a significant decrease (7.26%). It decreased in the moderate genotype (5.42%) and also in the tolerant genotype (1.47%).

When shaded, the tolerant genotype's response showed an increase in chlorophyll a and b; however, it refers to an increase in chlorophyll b compared to chlorophyll a. The increase in chlorophyll is due to the expression of the chlorophyll a/b binding protein, also known as the CAB gene, which is involved in forming the PSII light harvester (LHC II). This gene codes for complex proteins and binds to chlorophyll a/b (CAB) in PSII (LHC II). The tolerant genotypes could still adapt to absorbing leaf pigment compared to the sensitive and moderate ones. Even in low or limited light conditions, plants can increase productivity by inducing defense mechanisms (Zandalinas et al., 2018). Not in line with Shoukat et al. (2022), which showed that the corn chlorophyll a and b content placed in shaded conditions was reduced compared to plants placed in non-shaded conditions due to a reduction in photosynthetic activity.

Carotenoids play an important role in forming leaf pigments, and anthocyanins are pigments that prevent damage caused by ultraviolet radiation. In the tolerant genotype group, anthocyanins decreased, and carotenoids and total chlorophyll increased. High total chlorophyll in sweet corn plants will encourage plants to carry out more optimal photosynthesis. Significant differences existed in photosynthetic rate and stomatal conductance between the sensitive, moderate, and tolerant groups. At the same time, there were no significant differences in intercellular CO_2 between the sensitive, moderate, and tolerant genotypes. The photosynthetic rate in the tolerant, moderate and sensitive groups of sweet corn decreased significantly compared to no-shade. However, the photosynthetic rate in the 25% shade-tolerant group was 28.34 µmol CO_2 ms^{-1} higher than in the sensitive group at 26.50 µmol CO_2 ms^{-1} (Table 5). The deficit of light in hybrid sweet corn impacts decreasing the rate of photosynthesis and synthesis of carbohydrates.

Table 5. Plant physiological characteristics of 25 sweet corn genotypes under 0% and 25% shade conditions

Characteristic	Tolerant		Moderate		Sensitive	
	0%	25%	0%	25%	0%	25%
Chlorophyll a (mg g^{-1})	2.04^a	2.13^a	2.07^a	2.01^a	1.91^a	1.80^a
Chlorophyll b (mg g^{-1})	0.59^a	0.64^a	0.59^a	0.60^a	0.54^a	0.55^a
Anthocyanin (mg g^{-1})	0.08^a	0.07^a	0.07^a	0.06^a	0.07^a	0.07^a
Carotenoids (mg g^{-1})	0.51^a	0.53^a	0.56^a	0.50^a	0.49^a	0.45^a
Total chlorophyll (mg g^{-1})	2.64^a	2.76^a	2.67^a	2.58^a	2.45^a	2.34^a
Chlorophyll a/b ratio (mg g^{-1})	3.40^a	3.35^a	3.50^a	3.31^a	3.58^a	3.32^b
Stomatal density (mm^{-1})	87.98^a	93.62^a	86.92^a	90.62^a	85.49^a	86.98^a
Trichome density (mm^{-1})	0.73^a	0.75^a	0.50^a	0.54^a	0.54^a	0.41^b
Photosynthesis rate (µmol CO_2 ms^{-1})	33.71^a	28.34^b	33.87^a	27.63^b	33.16^a	26.50^b
Stomatal conductance (mol H_2O ms^{-1})	1.67^a	1.18^b	1.83^a	1.38^b	1.86^a	1.13^b
Intercellular CO_2 (mol H_2O ms^{-1})	334.94^a	335.54^a	343.02^a	338.59^a	348.81^a	35.22^a
TDS (°Brix)	12.88^a	11.21^b	12.82^a	10.76^b	12.64^a	8.35^b

Note: Means followed by the same letter in the row and in the same genotype group were not significantly different based on the contrast test (α = 5%)

The low photosynthetic rate of the sensitive genotype under shaded conditions probably occurred due to the limited photosynthetic (chlorophyll) content. The main decrease in photosynthesis rate was light intensity decrease; shade-tolerant maize has a high photosynthetic rate mechanism compared to shade-sensitive maize genotypes because the adaptability of plants differs depending on plant varieties (Yuan et al., 2022).

Stomatal conductance at 25% shade showed significantly different moderate tolerant and sensitive groups compared to control group (Table 5). Stomatal conductance indicates the degree of gas exchange required in photosynthesis. The conductance properties of stomata were closely related to the tolerance properties of plants to shade stress. It is related to decreased photosynthesis rate, thereby reducing the value of stomatal conductance. Photosynthesis, transpiration and stomatal conductance of maize under 60% shade stress were lower than those of control group or group without shaded condition (Gao et al., 2020). According to Shoukat et al. (2022), maize grown using greenhouse shade and without shade showed higher photosynthesis, transpiration and stomatal conductance in conditions without shelter compared to shade, while the concentration of CO_2 between cells was higher in the shade compared to conditions without shade and plants without shade had grain yields 9.71% higher than those under shaded conditions.

Stomata and trichomes' density of tolerant groups was higher than that of in sensitive group (Table 5). This indicates greater CO_2 diffusing capacity tolerant groups. The high number of stomata in tolerant genotypes is a process of plant adaptation to environmental conditions. Stomata density and trichomes in this research are influenced by genotype and environment (light). In line, Baharuddin et al. (2014) showed that stomata density in tomato plants of tolerant and shade-adapted genotypes significantly increased their stomata density because these genotypes could photosynthesize effectively. The density of trichomes in tolerant genotypes is a mechanism for plants to tolerate low light intensity. Shade 25% lowered the TDS content in all genotypes (Table 5). Shade inhibits the process of photosynthesis, thereby reducing the accumulation of fructose and glucose in sweet corn seeds and changing the level of TDS. According to Surtinah (2016), the more carbohydrates produced in photosynthesis, the higher the sugar content accumulates in the seeds.

Sensitive, moderate and tolerant groups significantly differed in yield component variables. The weight and unhusked weight of ears of tolerant, moderate and sensitive groups significantly decreased compared to that of ears of without shade group. However, at 25% shade, the tolerant group was higher than the moderate and sensitive groups (Table 6). Plants under shade stress experienced a decrease in yield between different genotypes. This also depended on the adaptability of sweet corn plants to stress conditions. The sensitive group showed the highest decrease in ears' unhusked weight (50.09%) compared to the moderate (32.43%) and tolerant (12.37%) groups. Ears were not filled because anthesis age appeared differently from silking age. It caused male flowers to die before the female flowers appeared. Environmental factors such as shade stress can extend the difference in the flowering age of hybrid sweet corn. Higher shade reduces the number of ears, resulting in a lower yield of hybrid sweet corn. Sa'adah et al. (2022) stated that the time difference between the appearance of male and female flowers on long maize results in cob hairs not being pollinated because the amount of pollen produced decreases or runs out. This affects the process of filling the seeds on the ears.

Moreover, during pre-tasselling, hybrid corn experiences a decrease in carbon fixation, resulting in higher amounts of carbon in the leaves than the amount transported to the reproductive

Table 6. Yield components of 25 sweet corn genotypes under 0% and 25% shade conditions

Characteristic	Tolerant		Moderate		Sensitive	
	0%	25%	0%	25%	0%	25%
Ear length (cm)	20.37[a]	18.82[a]	20.31[a]	17.08[b]	20.78[a]	15.37[b]
Ear diameter (cm)	4.44[a]	4.02[b]	3.84[a]	3.45[b]	3.65[a]	2.97[b]
Number of ears	2.13[a]	1.67[b]	1.89[a]	1.69[b]	1.93[a]	1.73[b]
Ear weight (g)	345.73[a]	298.65[b]	298.45[a]	190.09[b]	278.56[a]	154.87[b]
Ear unhusked weight (g)	231.90[a]	203.21[b]	192.08[a]	129.77[b]	179.22[a]	89.44[b]

Note: Means followed by the same letter in the row and in the same genotype group were not significantly different based on the contrast test (α = 5%)

tissue, reducing maize yield (Liang et al., 2020). The long-ears of tolerant group without shading were not significantly different at 25% shading, while those of the moderate and sensitive groups were significantly different. According to Fitrah et al. (2022), the length of corn ears in a *Eucalyptus* shaded environment decreased and the average ear length in the lines tested increased.

The tolerant group had the highest cotyledon diameter at 25% shade compared to the sensitive and moderate groups (Table 6). Sensitive groups under shaded conditions produced spindly ears, reducing ears diameter and yield. Several studies have also reported shading can reduce ear length and diameter (Araki et al., 2014; Liang et al., 2020; Ren et al., 2022). The number of ears of corn generally ranges from one to two per plant. Corn plants that were not under shade produced a lot of ears, at two ears per crop, while under 25% shade, the average plants in the tolerant, moderate and sensitive groups in one plant could only produce one productive ear. Sweet corn also has C4 plants, which have a high rate of photosynthesis and low photorespiration. This is related to shade, which affects photosynthesis: the light converted into energy is reduced, and some of it accumulates in the leaves and stems, inhibiting the flow of nutrients and consequently reducing the weight of the corn kernels. Shading impacts glycolysis, the tricarboxylic acid cycle, and other energy metabolism pathways, which can reduce energy supply and grain yield. Flexibility in energy metabolism can help increase maize resistance to shade stress (Gao et al., 2020). Shade stress greatly interferes with plant growth and productivity; the results of research conducted by shading with shade cloth around 40% of incoming light show a decrease in maize yields; during the vegetative and reproductive stages, it can reduce N accumulation and encourage the transport of N from other organs to grains and mitigate some of the effects of decreased N uptake (Zheng et al., 2022).

CONCLUSIONS

The finding shade level sweet corn selection was shade 25%. The genotypes can be split into three groups sensitive, moderate and tolerant. Tolerant groups provided highest increase in morpho-physiological characters and yield compared to the moderate and sensitive. In all genotype groups, morphological variables (number of leaves, leaf area, stem diameter and relative growth rate), physiological variables (stomata conductance, photosynthetic rate and TDS) and yield variables (length, diameter, number, weight and unhusked weight of ears) were significantly higher in the no-shade conditions than in the shaded conditions. Future studies can test sweet corn genotypes in agroforestry and intercropping systems with light intensity levels not exceeding 25% shade.

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