Selection of melon genotypes via selection indices that integrate yield, tolerance to biotic and abiotic stresses, and fruit quality

.

ABSTRACT

|  |
| --- |
| **Aims:** Select melon genotypes with ideal traits and compare two selection indices.**Study design:** 26 melon genotypes were evaluated using a randomized complete block design with three replications.**Place and Duration of Study:** In August 2023, the melon genotypes were transplanted inside greenhouse, located in Saltillo, Coahuila.**Methodology:** The inoculation with the fungus causing powdery mildew began in 15-day-old seedlings. Disease severity was visually assessed 28 days after transplant using a scale from 0 to 4, where 0 indicates high resistance and 4 indicates high susceptibility. In addition, the area under the disease progress curve was calculated. At 51 days after transplant, during flowering, the crop was subjected to severe heat stress for three days, and the variables relative chlorophyll content and leaf temperature were measured. When the fruit reached maturity, the following parameters were evaluated: days to first cut, fruit weight, total soluble solids, flavor, skin thickness, and pulp thickness.**Results:** The selection index highlighted genotypes 18, 27, 15, 20, 3, 12, 17, 29, and 13 as superior, while the MGIDI index selected genotypes 18, 27, 20, 12, 23, 29, 10, 5, and 15. The Harper-type melons (18, 27, and 15) stood out in both indices due to their combination of high yield, fruit quality, powdery mildew tolerance, chlorophyll content, and lower temperature under heat stress.**Conclusion:** The Harper-type melons were identified as the most promising. The discrepancy between the genotypes selected by the indices may be due to various factors related to the calculation methodology. |

*Keywords: melon, index, selection*

1. INTRODUCTION

Melons are a rich source of bioactive compounds, such as vitamin C, provitamin A, folic acid, phenolic compounds, fiber, minerals, and cucurbitacins, with beneficial effects in the prevention of cancer, depression, and ulcers and in strengthening the immune system [1].

However, melon production faces various challenges that affect yield and quality. Climate plays a fundamental role in agricultural productivity, as each species has a specific range of minimum, maximum, and optimal temperatures for its development. An increase in temperature can negatively affect the sexual reproduction of plants, reducing fertility in numerous species [2]. As a consequence, these alterations can lead to significant yield losses, impacting price variation and the well-being of farming families [3].

In addition to the impact of climate change, diseases are among the main limitations in melon production. Among these diseases, powdery mildew is one of the most important worldwide and frequently affects various cucurbit crops. This disease is caused by biotrophic fungi from the Erysiphaceae family, which infect leaves, stems, flowers, and fruits, significantly reducing both the quality and yield of production [4].

These adversities highlight the need to develop varieties with resistance to biotic and abiotic factors. A key challenge in melon breeding is genotype selection, as analyses often prioritize yield without considering other essential attributes, such as fruit quality, disease resistance, and tolerance to adverse conditions.

Various selection indices have been proposed to address this issue. For example, the selection index by [5] standardizes the data and assigns weights to variables according to their importance, combining these values into a single index to identify genotypes with the best overall performance on the basis of multiple traits [6], [7]. However, this approach may be limited by the difficulty of assigning appropriate weights and the potential multicollinearity among variables. In this situation, the multitrait genotype‒ideotype distance index (MGIDI) has emerged as a modern and efficient alternative. This index selects genotypes by measuring their distance to an ideal ideotype defined by the desired values for multiple traits, normalized between 0 and 100. It uses factor analysis to reduce dimensionality and avoid multicollinearity, efficiently and practically selecting genotypes with the best overall performance [8]. The MGIDI can be used for genotype selection by considering multiple traits, helping plant breeders make better strategic decisions [8], [9].

1. Materials and methods
	1. **Location**

In August 2023, the 26 melon genotypes were transplanted inside greenhouse 6, which is located in Saltillo, Coahuila, México (25.3934°N, 101.0005°W).

* 1. **Plant material**

A total of 26 melon genotypes, including Harper and Cantaloupe types, were cultivated within the Breeding Program of the Universidad Autónoma Agraria Antonio Narro. Cantaloupe melon genotypes: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 16, 19, 20, 21, 22, 23, 25, 26, 29. Harper melon**:** 15, 17, 18, 27.

* 1. **Fungal material**

Given the complexity of cultivating powdery mildew fungi, live plant tissue was used. Therefore, a collection was conducted in the surrounding area, including melon and squash crops, where infected leaves with powdery mildew were sampled. Preliminary identification of the causal agent was performed on the basis of its morphological characteristics, following [10].

**2.3.1 Inoculation**

A spore suspension of \**Podosphaera xanthii*\* was prepared and sprayed onto melon seedlings. Inoculation was carried out when the seedlings had a second true leaf (15 days after sowing), and it was repeated every third day for six inoculations.

The disease assessment was carried out visually 28 days after transplanting. To determine the response to the disease, Table 1 was used.

Table 1. Estimation of powdery mildew disease severity.

|  |  |  |  |
| --- | --- | --- | --- |
| Scale | Mold on the leaf surface (%) | Symptoms | Reaction |
| 0 | 0 | Absence of symptoms | High resistance |
| 1 | 1-12 | Very weak infection | Resistant |
| 2 | 13-25 | Weak infection | Tolerant |
| 3 | 26-50 | Moderate infection | Susceptible |
| 4 | 51-100 | Severe infection | High susceptibility |

[11]; [12].

* 1. **Evaluated variables**

Fifty-one days after transplanting (during the flowering stage), the crop was subjected to severe thermal stress for three days. During this period, the following variables were recorded:

Relative chlorophyll content: This was determined via FieldScout, which was previously calibrated to ensure measurement accuracy. Readings were taken from the middle part of the plant at different times of the day (9 AM, 2 PM, and 5 PM).

The plant temperature (°C) was measured via an infrared thermometer, which provides accurate and rapid readings of the leaf surface temperature. Measurements were also taken from the middle part of the plant at different times of the day.

Days to first harvest: The number of days from transplanting to the fruits reaching optimal maturity for harvest was recorded.

Fruit weight (g): The individual weight of each fruit was measured via a precision scale.

Equatorial and polar diameter of the fruit: The equatorial and polar diameters of each fruit were measured via a measuring tape. The polar diameter was determined from the peduncle end to the opposite end, whereas the equatorial diameter was recorded at the widest part of the fruit.

Mesh: A visual rating was given according to the scale proposed by the researcher, where 1 corresponded to minimal coverage, 3 to medium coverage, and 5 to total coverage.

Equatorial and polar diameter of the fruit cavity (cm): The melon was cut in half longitudinally, dividing it into two symmetrical sections. The polar diameter of the cavity was measured from the base of the cavity (near the peduncle) to the opposite end via a measuring tape. The equatorial diameter was determined at the widest part of the cavity.

Total soluble solids (°Brix): A sufficient sample was taken to cover the surface of the refractometer prism, and the reading was recorded.

Flesh color: Flesh color was evaluated via a scale ranging from 1--5, which was proposed by the researcher. On this scale, a value of 1 corresponds to a green color, whereas a value of 5 represents an intense orange color.

Flavor (1-5): A representative piece of melon pulp was cut, tasted, and rated on a scale from 1 to 5, where 1 indicates poor flavor and 5 indicates exceptional flavor.

Rind thickness (mm): A ruler was used to measure the thickness from the outer surface to the inner surface of the rind.

Flesh thickness (cm): Measured from the rind to the edge of the cavity.

The area under the disease progress curve (AUDPC) was calculated as follows [13]:

$$ABCPE=\sum\_{i=1}^{n-1}\frac{y\_{i}+y\_{i+1}}{2}x\left(t\_{i+1}-t\_{i}\right)$$

*yi* = disease evaluation (percentage) in the i-th observation

*t* = time (in days) in the i-th observation

𝑛 = total number of observations

The yield per hectare (t ha⁻¹) was determined by averaging the total weight of the fruits harvested for each genotype and multiplying by the plant density.

* 1. **Experimental design**

The 26 melon genotypes were established in a randomized complete block design with three replications.

* 1. **Statistical analysis**

**2.6.1 The selection index (SI)** according to [5]:

$$IS=\left\{\left[\left(Y\_{j}-M\_{j}\right)^{2}\*I\_{j}\right]+\left[\left(Y\_{i}-M\_{i}\right)^{2}\*I\_{i}\right]…\left[\left(Y\_{n}-M\_{n}\right)^{2}\*I\_{n}\right]\right\}^{1/2}$$

where *Y*j…*n* = the variables in Z units, *M*j…*n* = is the selection target, and *Ij…n* = selection intensity.

Table 2. Goals and intensities for calculating the selection index.

|  |  |  |
| --- | --- | --- |
| Variable | Goal | Intensity |
| Fruit weight (g) |  3 | 10 |
| Equatorial diameter of the fruit (cm) |  0 |  7 |
| Polar diameter of the fruit (cm) |  0 |  7 |
| Days to first harvest (days) | -1 |  8 |
| Yield (t ha-1) |  3 | 10 |
| Rind thickness (mm) |  0 |  5 |
| Flesh thickness (cm) |  1 |  7 |
| Equatorial diameter of the fruit cavity (cm) | -1 |  8 |
| Polar diameter of the fruit cavity (cm) | -1 |  8 |
| Total soluble solids (°Brix) |  3 | 10 |
| Relative chlorophyll content |  3 |  8 |
| Plant temperature (°C) |  3 |  5 |
| AUDPC | -3 | 10 |

* + - 1. **Heatmap**

To visualize the multivariate variation among genotypes and their clustering on the basis of phenotypic similarity, a heatmap was constructed via the pheatmap function from the **pheatmap** package [14] in R.

* + 1. **The multitrait genotype‒ideotype distance index (MGIDI) was calculated** according to [8]:

$$MGIDI\_{i}=\left[\sum\_{j=1}^{f}\left(γ\_{ij}-γ\_{j}\right)^{2}\right]^{0.5}$$

where $MGIDI\_{i}$ is the multitrait genotype‒ideotype distance index for the *i*th genotype set; $γ\_{ij}$ is the score of the *j*th genotype in the j-th factor (*i* = 1, 2..., *t*; *j* = 1, 2..., *f*), where *t* and *f* are the numbers of genotypes and factors, respectively; and $γ\_{j}$ is the *j*th score of the ideal genotype.

The strengths and weaknesses of a genotype were represented by the proportion of the MGIDI index of the *i*th genotype explained by the *j*th factor (ij), estimated as follows:

$$ω\_{ij}=\frac{\sqrt{D\_{ij}^{2}}}{\sum\_{j=1}^{f}\sqrt{D\_{ij}^{2}}}$$

where Dij is the distance between the *i*th genotype and the ideal genotype for the *j*th factor. Low contributions indicate that the traits associated with that factor are close to the ideal genotype.

The data manipulation and index calculation were performed in R software version 4.1.0 via the metan package [15].

1. results and discussion
	1. Selection index

The use of the selection index (SI) allowed the identification of the most promising genotypes from the trial by combining the joint expression of traits of interest into a single value, as initially proposed by [16] and [17]. According to [6], the genotypes that achieve the lowest values are closest to the desired ideotype. In this study, Harper-type melons 18, 27, 15, and 17 were closer to the ideal plant type, whereas the Cantaloupe-type genotypes 20, 3, and 12 occupied intermediate positions (Figure 1).

To visualize the superiority of the genotypes, a heatmap was generated (Figure 2), allowing for a visual comparison of genotype performance across different variables. This visualization confirms that harper-type genotypes exhibit superior performance in traits related to fruit quality and stress tolerance.

Harper-type melons presented relatively high values for yield, total soluble solids, polar and equatorial fruit diameters, and pulp thickness, all of which are directly related to commercial quality. Additionally, these genotypes presented lower disease severity (AUDPC), indicating greater genetic resistance [18]. Furthermore, these materials presented relatively high chlorophyll indices and relatively low plant temperatures under stress conditions. Previous studies have reported that these physiological parameters are closely related to stress tolerance; higher chlorophyll content is associated with increased photosynthetic efficiency and productivity under stress [19], whereas lower leaf temperatures reflect improved water regulation and reduced heat stress in plants [20].

Therefore, these results suggest that Harper-type genotypes not only present superior fruit quality but also exhibit physiological advantages that increase productive efficiency under adverse environmental conditions.

|  |
| --- |
|  |
| Figure 1. Values of the selection index proposed by [5] for 26 melon genotypes. |

|  |
| --- |
|  |
| Figure 2. Heatmap of standardized values (Z scores) for 26 melon genotypes evaluated across agronomic and physiological traits.*FW= Fruit weight; EDF= Equatorial diameter of the fruit; PDF= Polar diameter of the fruit; DFH= Days to first harvest; RT= Rind thickness; FT= Flesh thickness; EDFC= Equatorial diameter of the fruit cavity; PDFC= Polar diameter of the fruit cavity; TSS= Total soluble solids; RCC= Relative chlorophyll content; Temp= plant temperature; AUDPC= The area under the disease progress curve.* |

* 1. Multitrait Genotype–Ideotype Distance Index

Through the MGIDI, genotypes were selected on the basis of multiple agronomic and physiological traits. Additionally, the factorial analysis (Table No. 3) facilitated the interpretation of each genotype's strengths and weaknesses (Figure 3a). Thus, the 16 evaluated variables were grouped into five factors. Factor 1 (FA1) included productivity-related traits such as yield, average fruit weight, polar and equatorial fruit diameters, cavity diameter, and pulp thickness. Factor 2 (FA2) grouped quality attributes such as pulp color, flavor, and total soluble solids. Factor 3 (FA3) reflects leaf temperature, whereas factor 4 (FA4) comprises traits associated with tolerance to adverse conditions, including relative chlorophyll content, disease severity, netting, and rind thickness. Finally, Factor 5 (FA5) encompassed earliness-related traits such as days to first harvest and yield per hectare.

The genotypes selected through the MGIDI were 18, 27, 20, 12, 23, 29, 10, 5, and 15 (Figure 3b). Harper-type melons 18, 27, and 15 stood out because of their high contribution to FA1, reflecting their superior productivity. Additionally, genotypes 15 and 18 also presented high contributions to FA2, indicating that, beyond their productivity, they present quality attributes such as higher soluble solids content and better flavor traits that are highly valued by consumers [21]. On the other hand, although FA3 (leaf temperature) did not significantly contribute to most genotypes, its importance lies in identifying materials with better performance under heat stress, which is particularly relevant in warm regions or under climate change conditions [22]. With respect to tolerance to adverse conditions (FA4), genotypes 27 and 18 stood out once again, indicating their ability to withstand diseases (as evidenced by lower AUDPC values) and their higher relative chlorophyll content parameters, which are commonly associated with greater physiological resilience [23]. Finally, Factor FA5, associated with earliness, was particularly relevant for genotype 23, which stood out for its earlier harvest combined with acceptable yield, positioning it as a viable option for short production cycles.

The MGIDI has proven to be a highly practical tool for plant breeding programs, enabling an efficient, objective, and easily interpretable multivariate selection process by integrating multiple traits into a single value [24], [8], [9], [25]. Moreover, its practical implementation through statistical tools in R makes it an accessible index for researchers and breeders.

Table 3. Factor analysis (FA) factorial loadings based on the multitrait genotype–ideotype distance index

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Trait | FA1 | FA2 | FA3 | FA4 | FA5 |
| Fruit weight (g) | -0.97 | 0.02 | 0.17 | 0.07 | 0.06 |
| Equatorial diameter of the fruit (cm) | -0.95 | 0.01 | 0.09 | 0.09 | 0.05 |
| Polar diameter of the fruit (cm) | -0.93 | -0.04 | 0.16 | 0.01 | -0.03 |
| Mesh | -0.24 | -0.38 | -0.02 | -0.51 | -0.37 |
| Days to first harvest | 0.19 | 0.14 | -0.45 | -0.16 | 0.67 |
| Yield | -0.36 | -0.13 | 0.11 | 0 | 0.85 |
| Rind tickness | 0.07 | 0.13 | -0.5 | 0.66 | -0.07 |
| Flesh thickness | -0.78 | -0.11 | 0.5 | -0.06 | 0.04 |
| Flesh color | 0.15 | -0.84 | -0.18 | -0.03 | 0.2 |
| Equatorial diameter of the fruit cavity | 0.71 | -0.14 | 0.43 | -0.06 | -0.11 |
| Polar diameter of the fruit cavity | 0.91 | 0 | -0.11 | 0.07 | 0.02 |
| Total soluble solids | -0.23 | -0.7 | 0.52 | -0.2 | -0.1 |
| Flavor | 0.02 | -0.86 | 0.03 | -0.18 | -0.11 |
| Relative chlorophyll content | -0.04 | 0.22 | -0.13 | 0.76 | -0.08 |
| Plant temperature | -0.19 | 0.13 | 0.83 | -0.1 | -0.06 |
| AUDPC | -0.39 | -0.16 | 0.42 | 0.68 | -0.05 |



Figure 3a Strengths and weakness Figure 3b. Selection of genotypes on the basis of the MGIDI

1. Conclusion

Both the selection index and the MGIDI identified the Harper-type genotypes (18, 27, 20 and 12) as the closest to the expected ideotype, as they combined traits such as high yield, fruit quality, powdery mildew tolerance, and good performance under thermal stress. While the selection index quickly identifies outstanding genotypes in general terms, the MGIDI complements this evaluation by providing a more detailed analysis of the strengths and weaknesses.

The discrepancy between the genotypes selected by the indices may be due to several factors related to the calculation methodology, the weight of the evaluated variables, and the way each index prioritizes the traits.

References

1. Lija, M., Beevy, S. S. (2021). A review on the diversity of melon. Plant Science Today, 8(4), 995–1003.

2. Chaturvedi, P., Wiese, A. J., Ghatak, A., Drábková, L. Z., Weckwerth, W., Honys, D. (2021). Heat stress response mechanisms in pollen development. New Phytologist, 231, 571–85.

3. Nelson, G. C., Rosegrant, M. W., Koo, J. R., Robertson, R., Sulser, T. R., Zhu, T., et al. International Food Policy Research Institute. Climate change: The impact on agriculture and the costs of adaptation. Washington, D.C.: International Food Policy Research Institute (IFPRI); 2009 Oct.

4. Křístková, E., Lebeda, A., Sedláková, B. (2009). Species spectrum, distribution, and host range of cucurbit powdery mildews in the Czech Republic and in some other European and Middle Eastern countries. Phytoparasitica, 37, 337–350.

5. Barreto, H., Bolaños, J., Córdoba, H. (1991). Selection index program. Software operating guide. Regional Maize and Wheat Improvement Center, CIMMYT Publishing, Mexico City, Mexico, 27.

6. Rodríguez, P. G., Zavala, G. F., Gutiérrez, D. A., Treviño, R. J. E., Ojeda, Z. C., de la Rosa, L. A. (2013). Comparison of two types of selection in landraces. Mexican Journal of Agricultural Sciences, 4(4), 569-583.

7. Rodríguez, P. G., García, R. A., Reynaga, F. F. de J., Mendívil, M. J. E., Ochoa, M. A. R. (2023). Selection indices between agronomic and chemical traits in purple corn (Zea mays L.) hybrids in southern Sonora, Mexico. Scientific Anales, 84(1), 35-53.

8. Olivoto, T., Diel, M. I., Schmidt, D., Lúcio, A. D. (2022). MGIDI: a powerful tool to analyze plant multivariate data. Plant Methods, 18(121).

9. Singamsetti, A., Zaidi, P. H., Seetharam, K., Vinayan, M. T., Olivoto, T., Mahato, A., et al. (2023). Genetic gains in tropical maize hybrids across moisture regimes with multitrait-based index selection. Frontiers in Plant Science.

10. Lebeda, A. (1983). The genera and species spectrum of cucumber powdery mildew in Czechoslovakia. Phytopathol Z., 108:71-79.

11. James, W. C. (1971). An illustrated series of assessment keys for plant diseases, their preparation and usage. Canadian plant disease survey, 51(2), 39-65.

12. Abd Rabou, A. M., Hamed, A. A., Ramadan, M. M. (2021). Breeding Melon (Cucumis melo L.) for resistance to powdery mildew and fruit quality characteristics. Annals of Agric Sci, Moshtohor, 59(1), 75-86.

13. Simko, I., Piepho, H. P. (2012). The area under the disease progress stairs: calculation, advantage, and application. Phytopathology, 102(4):381-389.

14. Kolde R. pheatmap: Pretty Heatmaps. 2019.

15. Olivoto, T., Lúcio, A. D. (2020). metan: An R package for multi‑environment trial analysis. Methods in Ecology and Evolution, 11(6), 783-789.

16. Smith, H.F. (1936). A discriminant function for plant selection. Annals of Eugenics, 7, 240-250.

17. Hazel, L. N. (1943). The Genetic Basis for Constructing Selection Indexes. Genetics, 28, 476-490.

18. Bryson, R. J., Sylvester-Bradley, R., Scott, R. K., Paveley, N. D. (1995). Reconciling the effects of yellow rust on yield of winter wheat through measurements of green leaf area and radiation interception. Aspects of Applied Biology, 42, 9-18.

19. Park, B., Wi, S., Chung, H., Lee, H. (2024). Chlorophyll Fluorescence Imaging for Environmental Stress Diagnosis in Crops. Sensors, 24(1442).

20. Blum, A. (2009). Effective water use (EUW) and not water-use efficiency (WUE) is the target of crop yield improvement under drought stress. Field Crops Research, 112, 119–123.

21. García, M. V., Cano, R. P., Reyes, C. J. L. (2019). Harper melon hybrids have higher quality and postharvest life compared to commercial hybrids. Chapingo Journal, Horticulture Series, 25(3), 185–197.

22. Hatfield, J. L., Prueger, J. H. (2015). Temperature extremes: Effect on plant growth and development. Weather and Climate Extremes, 10, 4–10.

23. Rolando, J. L., Ramírez, D. A., Yactayo, W., Monneveux, P., Quiroz, R. (2015). Leaf greenness as a drought tolerance related trait in potato (Solanum tuberosum L.). Environmental and Experimental Botany, 110, 27-35.

24. Olivoto, T., Nardino, M. (2021). MGIDI: toward an effective multivariate selection in biological experiments. Bioinformatics, 37(10), 1383-1389.

25. Pallavi, M., Maruthi Prasad, B. P., Shanthi, P., Reddy, V. L. N., Nirmal Kumar, A. R. (2024). Multi trait genotype- ideotype distance index (MGIDI) for early seeding vigor and yield related traits to identify elite lines in rice (Oryza sativa L.). Indian Society of Plant Breeders, 15(1), 120-131.