Pesquisa Agropecuária Brasileira

ISSN 1678-3921

Journal homepage: www.embrapa.br/pab

For manuscript submission and journal contents, access: www.scielo.br/pab

Genetics/ Original Article

Predicting genetic gains for multi-trait selection in durum wheat under semiarid conditions

Abstract – The objective of this work was to evaluate the effectiveness of seven selection indices combined with different economic weights in improving agronomic traits in durum wheat. The experiment was carried out at the agricultural experimental station of Institut Technique des Grandes Cultures in Sétif, Algeria, during the 2022/2023 cropping season. A total of 59 genotypes were evaluated in a randomized complete block design with three replicates. A significant genetic variability was observed, with a high broad-sense heritability for days to heading, plant height, chlorophyll content, and straw yield, indicating a strong potential for selection. The Mulamba & Mock index combined with the variation index and heritability effectively reduced days to heading and increased chlorophyll content. The Cruz index weighted by heritability was the most effective for flag leaf area, while the Cruz and Smith & Hazel indices combined with the variation index improved plant height. For yield traits, including grain yield and spike weight, the Smith & Hazel, Mulamba & Mock, and Pesek & Baker indices led to the highest gains when weighted by standard deviation and the genotypic coefficient of variation. Biomass traits, such as straw yield and aboveground biomass, are best improved by the Smith & Hazel and Williams indices, particularly combined with the variation index. The coincidence analysis shows a strong agreement among selection strategies, identifying superior genotypes for semiarid environments.

Index terms: *Triticum durum*, agronomic traits, economic weights, heritability, selection indices.

Previsão de ganhos genéticos para seleção multicaracterística em trigo duro sob condições semiáridas

Resumo – O objetivo deste trabalho foi avaliar a eficácia de sete índices de seleção combinados com diferentes pesos econômicos na melhora de caracteres agronômicos em trigo duro. O experimento foi conduzido na estação agronômica experimental do Institut Technique des Grandes Cultures, em Sétif, na Argélia, durante a safra de 2022/2023. Foram avaliados 59 genótipos em delineamento de blocos ao acaso, com três repetições. Observou-se ampla variabilidade genética, com alta herdabilidade em sentido amplo para dias até o espigamento, altura de plantas, teor de clorofila e rendimento de palha, o que indica bom potencial de seleção. O índice de Mulamba & Mock combinado com o índice de variação e a herdabilidade reduziu os dias até o espigamento e aumentou o teor de clorofila. O índice de Cruz ponderado pela herdabilidade foi mais eficaz para a área da folha bandeira, enquanto os índices de Cruz e Smith & Hazel combinados com o índice de variação melhoraram a altura de plantas. Para caracteres de rendimento, como rendimento de grãos e peso de espiga, os índices de Smith & Hazel, Mulamba & Mock e Pesek & Baker

Abou-bakr Rabti (✉)
University of Mohamed-Cherif Messaadia, Institute of Agriculture and Veterinary Sciences, Souk Ahras, Algeria.
E-mail: a.rabti@univ-soukahras.dz

Zine El Abidine Fellahi
[1]University Mohamed El Bachir El Ibrahimi, Faculty of Natural, Life and Earth Sciences and the Universe, Department of Agronomic Sciences, Bordj Bou Arreridj, Algeria.
E-mail: zineelabidine.fellahi@univ-bba.dz
[2]University of Ferhat Abbas, Valorization of Natural Biological Resources Laboratory, Sétif-1, Sétif, Algeria.

✉ Corresponding author

Received
April 26, 2025

Accepted
November 24, 2025

How to cite
RABTI, A.; FELLAHI, Z.E.A. Predicting genetic gains for multi-trait selection in durum wheat under semiarid conditions. **Pesquisa Agropecuária Brasileira**, v.61, e04073, 2026. DOI: https://doi.org/10.1590/S1678-3921.pab2026.v61.04073.

geraram maiores ganhos quando ponderados pelo desvio-padrão e o coeficiente de variação genotípico. Caracteres de biomassa, como rendimento de palha e biomassa aérea, são aprimorados pelos índices de Smith & Hazel e Williams, particularmente quando combinados com o índice de variação. A análise de coincidência confirma a concordância entre as estratégias de seleção, identificando genótipos superiores para ambientes semiáridos.

Termos para indexação: *Triticum durum*, características agronômicas, pesos econômicos, herdabilidade, índices de seleção.

Introduction

Durum wheat (*Triticum turgidum* subsp. *durum*) plays a vital role in Algerian agriculture due to its use in staple foods such as couscous and pasta, which are central to the national diet (Bekaddour et al., 2026). Its strategic importance for food security and rural livelihoods has heightened with the rising demand for cereal-based products (Grosse-Heilmann et al., 2024). However, durum wheat production in Algeria faces critical challenges posed by harsh climatic conditions – chiefly recurring drought and elevated temperatures (Kourat et al., 2022). These abiotic stresses increase evapotranspiration, disrupt irrigation, and negatively impact key developmental stages such as flowering and grain filling, leading to yield reductions and quality losses (Fellahi et al., 2024).

In this scenario, breeding efforts have prioritized the development of drought-tolerant and high-yielding cultivars suited to local agro-climatic conditions. These programs aim to enhance crop resilience and performance through the integration of diverse germplasm and modern selection tools (De Vita & Taranto, 2019). Optimizing yield also requires taking into account plant density, management practices, and traits that confer tolerance to drought, pests, and diseases, promoting adaptation across the diverse zones of Algeria (Melash et al., 2023).

Despite being traditionally used, mono-trait selection has often proven to be inefficient in complex and variable environments due to genotype × environment interactions (Hannachi & Fellahi, 2023). According to the same authors, index-based selection is a strong alternative since it integrates multiple traits into a composite score, enabling simultaneous improvement in yield, stress tolerance, and quality. This multivariate approach is especially relevant for breeding under stress-prone Mediterranean climates.

Several indices have been widely used for crop improvement. The classical Smith (1936) & Hazel (1943) index applies fixed economic weights and has shown predictive utility in silage maize (*Zea mays* L.). However, more flexible indices, such as the Mulamba & Mock (1978) rank-sum method, can offer better-balanced genetic gains (Peixoto et al., 2021). Similarly, the Williams (1962) base index has proven to be effective in optimizing multiple traits simultaneously, especially grain yield (Hannachi & Fellahi, 2023). Other noteworthy indices include Elston's (1963) free-weight index, which permits dynamic trait weighting, a practical advantage in changing environments. The Pesek & Baker (1971) index of desired gains stands out for targeting specific breeding goals, although it may be outperformed by more general indices in crops with complex trait interactions. The multiplicative index by Subandi et al. (1973) has shown robust results in various crops, such as lettuce (*Lactuca sativa* L.), optimizing contributions from all traits (Peixoto et al., 2020). Finally, the genotype-ideotype distance index of Cruz (2006b) allows breeders to select genotypes that closely match an ideal profile-balancing yield, quality, and stress resilience.

The integration of such indices has significantly improved selection efficiency in plant breeding, allowing the identification of superior genotypes that meet both agronomic and environmental challenges. Therefore, whether using classical or flexible indices, index-based selection remains a cornerstone for accelerating genetic gains, especially under climate-stressed conditions.

The objective of this work was to evaluate the effectiveness of seven selection indices combined with different economic weights in improving agronomic traits in durum wheat.

Materials and Methods

The field experiment was carried out during the 2022/2023 cropping season at the agricultural experimental station of Institut Technique des Grandes Cultures in Sétif, Algeria (36°09'N, 5°21'E, at 1,081 m above sea level). Fifty-nine durum wheat genotypes, including landraces and improved cultivars, were evaluated (Table 1). The trial followed a randomized complete block design with three replicates. Each plot consisted of two 2.0 m rows spaced 0.2 m apart. Sowing was performed on December 15, 2022, and recommended agronomic practices for the region were adopted (Rabti et al., 2020). Before sowing, 80 kg ha^{-1} monoammonium phosphate (52% P_2O_5 + 12% nitrogen) were applied, followed by 80 kg ha^{-1} urea (46% N) at tillering. For weed control, the commercial fungicide Zoom (150 g ha^{-1} dicamba + triasulfuron) and herbicide Traxos (1.2 L ha^{-1} pinoxaden + clodinafop-propargyl + cloquintocet-mexyl) were applied.

Data were recorded at key growth stages. Days to heading were counted from January 1 to 50% spike emergence. Flag leaf area (cm^2) was estimated according to Spagnoletti Zeuli & Qualset (1990) from five leaves per plot, using the formula:

Flag leaf area = 0.749 × (length × width)

Chlorophyll content was measured considering the soil plant analysis development (SPAD) at anthesis using the SPAD-502 meter (Konica Minolta, Osaka, Japan). At maturity, 1.0 m of each plot was sampled to determine aboveground biomass (g m^{-2}), spike number per square meter, spike weight (g) per square meter, number of grains per spike, and grain yield (g) per square meter. Straw yield (g) per square meter was computed as the difference between aboveground biomass and grain yield. Plant height (cm) was measured before harvest, whereas thousand kernel weight (g) was obtained from 250 grains.

Table 1. Name, origin, and year of release of the 59 durum wheat (*Triticum durum*) genotypes evaluated during the 2022/2023 cropping season at the experimental station of Institut Technique des Grandes Cultures in Sétif, Algeria.

N°	Name	Origin(1)	Year(2)	N°	Name	Origin(1)	Year(2)
1	Adjini	Algeria	1937	31	Mansourah	Algeria	2012
2	Ammar 1	ICARDA	2010	32	Massara 1	ICARDA	1988
3	Ammar 6	ICARDA	2010	33	Massinissa	Algeria	2012
4	Beliouni 3258	Algeria	1958	34	Maestrale	Italy	2004
5	Beni Mestina	Algeria	2015	35	Mohamed Ben Bachir	Algeria	1931
6	Bidi 17	Algeria	1930	36	Megress	Algeria	2011
7	Bolenga	Spain	1997	37	Mexicali 75	CIMMYT	1975
8	Bousselam	CIMMYT-ICARDA	1995	38	Mimono	Italy	–
9	Cannizzo	Italy	1998	39	Odisseo	Italy	2011
10	Hedba 3	Algeria	1921	40	Ofanto	Italy	1990
11	Capeiti 8	Italy	1940	41	Ardente	France	1984
12	Carioca	France	1999	42	Orjaune	France	1995
13	Sham 3	ICARDA	1995	43	Oued Zenati 368	Algeria	1936
14	Chen ‘s’	CIMMYT	1983	44	Oum Rabi 5	ICARDA	1993
15	Ciccio	Italy	1996	45	Poggio	Italy	–
16	Cirta	Algeria	2004	46	Polonicum	France	1973
17	Colosseo	Italy	1995	47	Sahel	CIMMYT	1977
18	Core	Italy	2008	48	Saoura	ICARDA	2012
19	Djenah Khotifa	Algeria	1955	49	Sarragola	Italy	2002
20	Eider	CIMMYT-ICARDA	1997	50	Simeto	Italy	1988
21	Grecale	Italy	2002	51	Setifis	Algeria	2011
22	Gloire de Montgolfier	Algeria	1960	52	Sigus	ICARDA	2015
23	GTA dur	CIMMYT	1983	53	Cyprus	Cyprus	1992
24	Guemgoum Rkhem	Algeria	1960	54	Tajdid	Algeria	–
25	Haurani 27	Jordan	1976	55	Vitron	Spain	1986
26	Inrat 69	Tunisia	1969	56	Waha	ICARDA	1984
27	Iride	Italy	1996	57	Wahbi	Algeria	2011
28	Karim	Tunisia	1985	58	Boutaleb	Algeria	2016
29	Kebir	ICARDA	1993	59	Oued El Bared	Algeria	2016
30	Langlois	Algeria	1925				

(1)ICARDA, International Center for Agricultural Research in the Dry Areas; and CIMMYT, International Maize and Wheat Improvement Center. (2)Year of release in the country/institute of origin.

DOI: 10.1590/S1678-3921.pab2026.v61.04073

The data were analyzed using the analysis of variance (ANOVA) to assess genotype effects. From mean squares, phenotypic (σ^2_p), genotypic (σ^2_g) and environmental (σ^2_e) variances were estimated to compute phenotypic (CV_p), genetic (CV_g), and environmental (CV_e) coefficients of variation (CVs), as well as the variation index and broad-sense heritability (h^2_{bs}), according to Cruz (2006a):

$$CV_p\ (\%) = 100 \times (\sqrt{\sigma^2_p}/\mu)$$

$$CV_g\ (\%) = 100 \times (\sqrt{\sigma^2_g}/\mu)$$

$$CV_e\ (\%) = 100 \times (\sqrt{\sigma^2_e}/\mu)$$

$$\text{Variation index} = CV_g / CV_e$$

$$h^2_{bs}\ (\%) = 100 \times (\sigma^2_g/\sigma^2_p)$$

where μ is the trait mean. CV values were classified as low (<10%), moderate (10–<20%), or high (≥20%), while heritability was considered low (<30%), moderate (30–<60%), or high (≥60%).

Means were compared using Tukey's honestly significant difference test, at a 5% significance level ($HSD_{5\%}$). Traits with nonsignificant ANOVA results were excluded from the gain analysis. Genetic gain was predicted assuming a 10% selection pressure. Direct selection gains were estimated according to Cruz (2006b), as:

$$\text{Selection gains}_i = (X_{si} - X_{oi}) \times h^2_i = DS_i \times h^2_i$$

where X_{si} and X_{oi} are the means of the top 10% and the whole population for trait i, DS_i is the selection differential, and h^2_i is broad-sense heritability.

Seven selection indices were applied: classical of Smith & Hazel (Smith, 1936; Hazel, 1943), rank-sum of Mulamba & Mock (1978), base of Williams (1962), desired gains of Pesek & Baker (1971), genotype-ideotype distance of Cruz (2006b), free weight of Elston (1963), and multiplicative of Subandi et al. (1973). The first five were evaluated under four weighting criteria – economic weight equal to 1 (W1), CV_g, variation index, and h^2_{bs} –, whereas the last two were applied without economic weights. All statistical analyses were performed using the GENES software (Cruz, 2013).

Results and Discussion

The ANOVA revealed significant ($p<0.05$) to highly significant ($p<0.01$) differences among durum wheat genotypes for most traits, except for number of grains per spike (Table 2). The variability in days to heading emphasized the critical role of this trait in synchronizing crop development with environmental conditions to optimize yield (Fellahi et al., 2024). Chlorophyll content and flag leaf area, essential for grain filling and yield stability under semiarid conditions, emerged as crucial contributors to photosynthetic efficiency and biomass accumulation, corroborating earlier findings (Fischer et al., 2014).

Table 2. Results of the analysis of variance and mean values of the traits evaluated in durum wheat (*Triticum durum*) genotypes.

Source of variation[1]	Block	Treatment	Residual	CV (%)[2]	Mean	$HSD_{5\%}$[3]
DF	2	58	116	–	–	–
HD	0.63	46.39**	1.47	0.95	127.49	4.14
CC	125.29	89.59**	27.04	14.53	35.78	17.79
FLA	34.99	38.54**	15.55	19.57	20.15	13.49
PH	412.99	446.25**	84.69	10.23	89.96	31.48
SN	24,253.11	20,074.23**	11,877.53	31.06	350.90	372.78
SW	491.40	553.98*	353.37	31.15	60.35	64.30
NGS	22.53	102.71ns	82.13	29.31	30.93	31.00
TKW	21.38	31.13**	14.04	11.13	33.68	12.82
GY	123.18	206.05**	110.89	30.15	34.92	36.02
SY	3,843.18	937.67**	320.00	30.87	57.95	61.19
BIO	6,923.82	2,150.19**	1,225.20	29.53	118.53	119.73

[1]DF, degrees of freedom; HD, days to heading; CC, chlorophyll content; FLA, flag leaf area; PH, plant height; SN, spike number; SW, spike weight per square meter; NGS, number of grains per spike; TKW, thousand kernel weight; GY, grain yield; SY, straw yield; and BIO, aboveground biomass. [2]Coefficient of variation. [3]Tukey's honestly significant difference test, at a 5% significance level. * and **Significant effect at 5 and 1%, respectively. nsNonsignificant.

Thousand kernel weight and spike number and weight presented a significant variability, underlining the utility of these traits as selection criteria due to their direct association with yield potential. Similarly, straw yield and aboveground biomass indicated plant vigor and resource-use efficiency, in alignment with studies linking biomass partitioning to yield adaptation (Bogale & Tesfaye, 2016). In contrast, no differences were observed for number of grains per spike as noted by Slafer et al. (2022), suggesting a strong environmental control over reproductive traits. Therefore, selection focused solely on number of grains per spike may be inefficient without a broader genetic diversity, i.e., through introgression from wild relatives.

Genotypes differed significantly from each other regarding the evaluated traits (Figure 1). Days to heading ranged from 123 days for G13 to 136 days for G1, with a mean of 127.49. Chlorophyll content varied from 25.63 SPAD in G59 to 46.03 SPAD in

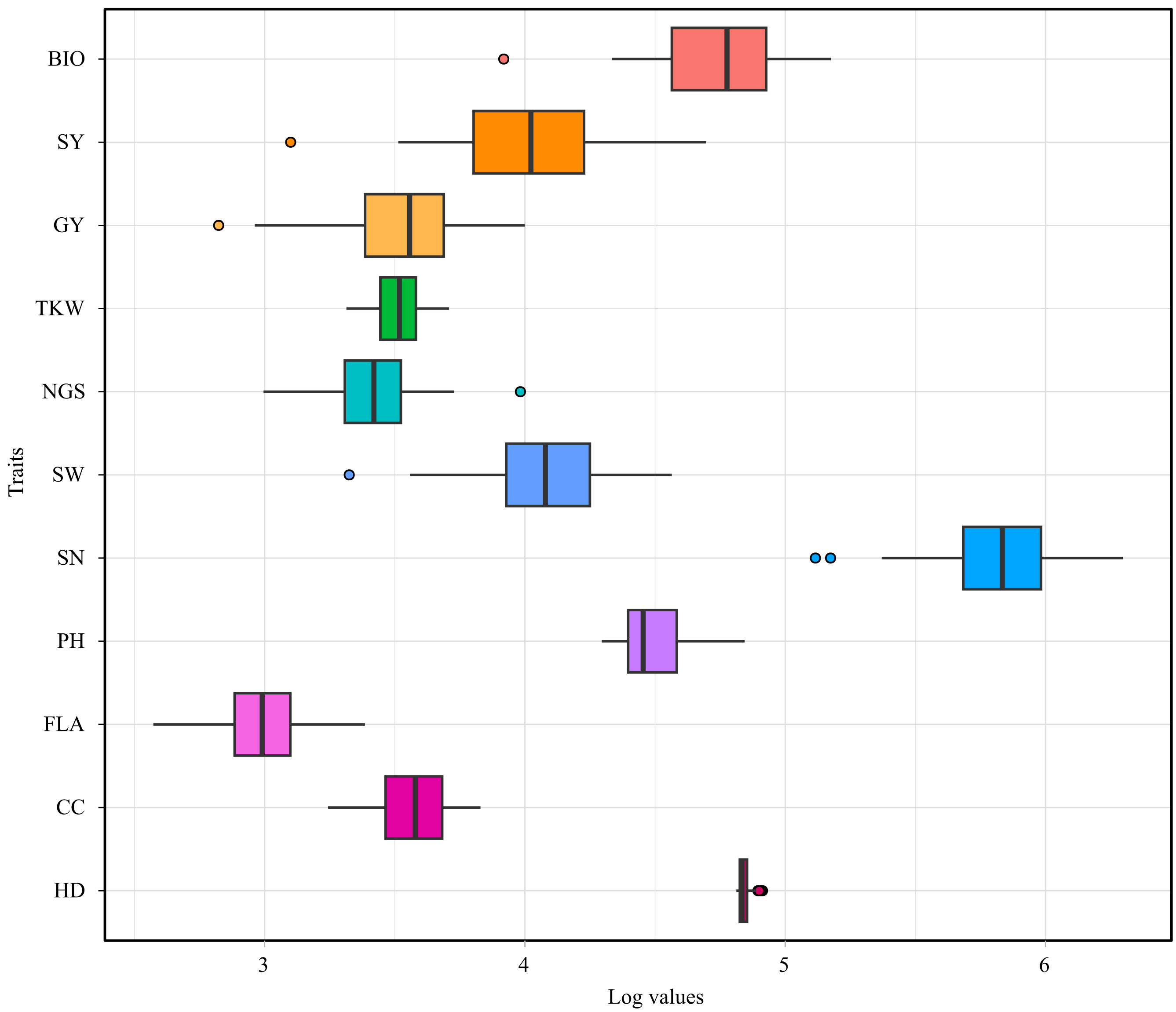

Figure 1. Box plot of variation of various traits of durum wheat (*Triticum durum*) genotypes. BIO, aboveground biomass; SY, straw yield; GY, grain yield; TKW, thousand kernel weight; NGS, number of grains per spike; SW, spike weight per square meter; SN, spike number; PH, plant height; FLA, flag leaf area; CC, chlorophyll content; and HD, days to heading.

G49, showing a mean of 35.78. Flag leaf area went from 13.10 cm^2 for G51 to 29.53 cm^2 for G43, with a mean of 20.15. Plant height varied from 73.33 cm for G40 to 127 cm for G18, with a mean of 89.96. As to spikes, the number per square meter ranged from 166.67 for G39 to 543.33 for G42, with a mean of 350.90, whereas weight varied from 27.80 g m^{-2} for G39 to 96 g m^{-2} for G42, with a mean of 60.3. The number of grains per spike went from 20 for G23 to 53.67 for G35, showing a mean of 30.93. Thousand kernel weight varied from 27.50 g for G49 to 40.80 g for G32, with a mean of 33.68. In addition, grain yield ranged from 16.83 g m^{-2} for G23 to 54.57 g m^{-2} for G42, showing a mean of 34.92. Straw yield went from 22.20 g m^{-2} for G39 to 109.57 g m^{-2} for G12, with a mean of 57.95, while aboveground biomass ranged from 50.33 g m^{-2} for G19 to 177 g m^{-2} for G42, with a mean of 118.53. The wide variation observed, exceeding $HSD_{5\%}$ thresholds (Table 3), confirms substantial genetic diversity among the studied genotypes and potential for selection in breeding. However, environmental influence remains significant, which means that distinguishing between genetic and environmental effects is essential to improve heritability estimates and guide selection for resilient durum wheat.

CV_p, CV_g, and CV_e revealed distinct variability patterns among traits (Table 3). CV_p values were: high for straw yield, spike number, spike weight, grain yield, and aboveground biomass, indicating considerable overall variability; intermediate for chlorophyll content, flag leaf area, plant height, and number of grains per spike; and low for days to heading and thousand kernel weight. CV_g was highest for straw yield, moderate for most traits, and lowest for days to heading, number of grains per spike, and thousand kernel weight, suggesting a limited genetic diversity. CV_e was high for spike number, spike weight, number of grains per spike, straw yield, grain yield, and aboveground biomass, being intermediate for most of the other traits, but low for days to heading. Overall, the high CV_p and CV_g values for straw and grain yield reflected a strong genetic potential for selection (Shamuyarira et al., 2022), whereas the low variability for days to heading and thousand kernel weight indicated stability and a narrow genetic base (Fischer et al., 2014). The high CV_e for spike weight and grain yield highlighted a strong environmental influence that may reduce selection efficiency.

Measure h^2_{bs} was high for days to heading, chlorophyll content, plant height, and straw yield, reflecting a strong genetic control and stable expression, consistent with a previous report (Fernandes et al., 2022). The values of h^2_{bs} were moderate for flag leaf area, spike weight, grain yield, and thousand kernel weight, indicating combined

Table 3. Genetic, phenotypic, and environmental parameters for various traits measured in durum wheat (*Triticum durum*) genotypes at the experimental station of Institut Technique des Grandes Cultures in Sétif, Algeria(1).

Trait	σ^2_p	σ^2_g	σ^2_e	CV_p (%)	CV_g (%)	CV_e (%)	VI	h^2_{bs} (%)
HD	15.46	14.98	1.47	3.08	3.04	0.95	3.20	96.84
CC	29.86	20.85	27.04	15.27	12.76	14.53	0.88	69.82
FLA	12.85	7.66	15.55	17.79	13.74	19.57	0.70	59.66
PH	148.75	120.52	84.69	13.56	12.20	10.23	1.19	81.02
SN	6,691.41	2,732.23	11,877.53	23.31	14.90	31.06	0.48	40.83
SW	184.66	66.87	353.37	22.52	13.55	31.15	0.44	36.21
NGS	34.24	6.86	82.13	18.92	8.47	29.30	0.29	20.03
TKW	10.38	5.70	14.04	9.57	7.09	11.13	0.64	54.89
GY	68.68	31.72	110.89	23.73	16.13	30.16	0.53	46.19
SY	312.56	205.89	320.00	30.51	24.76	30.87	0.80	65.87
BIO	716.73	308.33	1225.02	22.59	14.81	29.53	0.50	43.02

(1)HD, days to heading; CC, chlorophyll content, obtained by the Soil Plant Analysis Development; FLA, flag leaf area (cm^2); PH, plant height (cm); SN, spike number per square meter; SW, spike weight (g) per square meter; NGS, number of grains per spike; TKW, thousand kernel weight (g); GY, grain yield (g) per square meter; SY, straw yield (g) per square meter; BIO, aboveground biomass (g) per square meter; σ^2_p, phenotypic variance; σ^2_g, genotypic variance; σ^2_e, environmental variance; CV_p, phenotypic coefficient of variation; CV_g, genetic coefficient of variation; CV_e, environmental coefficient of variation; VI, variation index; and h^2_{bs}, broad-sense heritability.

genetic and environmental influences, but low for grains per spike, confirming major environmental effects and a complex genetic control (Mizuno et al., 2021). These patterns were further supported by the variation index, whose ratios were high for days to heading, plant height, chlorophyll content, and straw yield, but low for grains per spike, highlighting the environmental sensitivity of this trait. Overall, high-heritability traits appeared most suitable for selection, whereas the moderate-to-low ones require evaluation across multiple environments to guarantee reliable genetic gains (Fernandes et al., 2022).

The expected genetic gains for key agronomic traits in durum wheat were obtained using multiple selection indices with different economic weights, as shown in Table 4. For traits requiring reduction, such as days to heading, there was a decrease of -2.53 and -2.36% when the Mulamba & Mock index was paired with the variation index and with h^2_{bs}, respectively. For traits that needed to be improved, as chlorophyll content, the Mulamba & Mock index led to gains up to 9.96%, when combined with the variation index, and to 9.72% with h^2_{bs}, while the Pesek & Baker index provided gains of 3.19% across all weights, indicating

Table 4. Estimates of genetic gains (%) obtained through selection indices × economic weights for durum wheat (*Triticum durum*) genotypes.

Index(1)	Economic weight(2)	Trait(3)									
		HD	CC	FLA	PH	SN	SW	TKW	GY	SY	BIO
	GS	-2.99	17.88	20.30	-12.47	17.45	13.52	9.08	18.90	40.66	16.74
SHI	CV_g	0.93	-4.13	9.08	11.84	15.80	8.66	-3.98	8.05	28.65	14.41
	SD_g	-0.46	-0.55	6.30	4.99	16.74	11.37	-3.31	12.76	24.79	14.81
	h^2_{bs}	2.37	-6.00	11.91	13.80	13.31	7.82	-4.42	5.67	32.47	15.11
	VI	4.31	-11.75	12.16	19.15	5.39	1.65	-3.44	-2.17	40.66	13.98
	W1	0.93	-4.13	9.08	11.84	15.80	8.66	-3.98	8.05	28.65	14.41
MMI	CV_g	-0.96	5.27	2.87	-5.82	11.63	12.94	-0.84	16.31	14.61	12.49
	SD_g	-1.68	3.43	1.70	-1.57	17.09	12.62	-3.84	15.87	15.65	12.65
	h^2_{bs}	-2.36	9.72	-1.25	-6.52	8.59	10.71	1.77	14.56	11.73	10.23
	VI	-2.53	9.96	-3.52	-6.67	7.36	8.21	0.53	11.24	8.25	7.61
	W1	-1.98	6.40	1.35	-5.02	11.85	13.00	0.14	17.04	12.76	11.97
PBI	CV_g	-1.89	3.19	-1.67	-5.97	13.34	12.48	-2.39	17.77	9.33	10.55
	SD_g	-1.89	3.19	-1.67	-5.97	13.34	12.48	-2.39	17.77	9.33	10.55
	h^2_{bs}	-1.89	3.19	-1.67	-5.97	13.34	12.48	-2.39	17.77	9.33	10.55
	VI	-1.89	3.19	-1.67	-5.97	13.34	12.48	-2.39	17.77	9.33	10.55
	W1	-1.89	3.19	-1.67	-5.97	13.34	12.48	-2.39	17.77	9.33	10.55
WI	CV_g	-0.46	-0.55	6.30	4.99	16.74	11.37	-3.31	12.76	24.79	14.81
	SD_g	-0.42	-3.48	6.76	5.64	17.09	11.32	-2.45	13.35	22.05	13.90
	h^2_{bs}	1.02	-2.45	6.76	11.19	15.28	9.35	-3.90	9.42	30.21	15.31
	VI	2.24	-7.70	9.05	15.40	12.63	7.87	-3.02	7.27	36.15	16.32
	W1	-0.46	-0.55	6.30	4.99	16.74	11.37	-3.31	12.76	24.79	14.81
CI	CV_g	-0.37	-3.68	7.65	6.19	14.73	11.78	0.50	13.69	25.58	15.29
	SD_g	0.13	-4.96	6.96	6.14	15.31	11.71	-0.19	13.90	25.73	15.29
	h^2_{bs}	4.18	-8.19	16.06	15.60	3.87	2.48	0.28	-0.79	35.79	12.91
	VI	5.49	-9.84	14.25	21.65	1.19	-2.05	-1.54	-7.45	37.73	10.80
	W1	1.78	-4.96	15.48	6.74	12.86	10.21	-0.99	10.16	28.41	15.23
EI		-0.37	-3.68	7.65	6.19	14.73	11.78	0.50	13.69	25.58	15.29
SI		-1.89	1.65	0.97	-1.67	14.12	13.24	-1.26	17.97	19.42	14.22

(1)SHI, Smith & Hazel index; MMI; Mulamba & Mock index; PBI, Pesek & Baker index; WI, Williams index; CI, Cruz index; EI, Elston index; and SI, Subandi index. (2)GS, gain from direct selection; CV_g, genetic coefficient of variation; SD_g, genetic standard deviation; h^2_{bs}, broad-sense heritability; VI, variation index; and W1, economic weight equal to 1. (3)HD, days to heading; CC, chlorophyll content, obtained by the Soil Plant Analysis Development; FLA, flag leaf area (cm^2); PH, plant height (cm); SN, spike number per square meter; SW, spike weight (g) per square meter; TKW, thousand kernel weight (g); GY, grain yield (g) per square meter; SY, straw yield (g) per square meter; and BIO, aboveground biomass (g) per square meter.

a balanced choice for the cited trait. The Cruz index yielded the highest gain for flag leaf area of 16.06% with h^2_{bs}, and, as observed for the Smith & Hazel index, improved plant height, particularly under weighting by the variation index and h^2_{bs}. For yield-related traits, as spike number, the Smith & Hazel index weighted by genetic standard deviation (SD_g) led to maximum gains of 16.74%, whereas both the Mulamba & Mock and Williams indices resulted in gains of 17.09%. The Cruz index also allowed moderate gains when weighted by SD_g and CV_g. However, the highest gains in spike weight and grain yield (13.24 and 17.97%, respectively) were obtained by the Subandi index. Although the Mulamba & Mock and Pesek & Baker indices also provided substantial gains across these traits, the latter index showed a consistent and stable performance across weights. In addition, the Smith & Hazel and Williams indices led to the best results for traits enhancing biomass production, such as straw yield and aboveground biomass; specifically, the Williams index caused a 16.32% increase in biomass when combined with the variation index. Overall, the Smith & Hazel, Cruz, and Williams indices proved to be highly effective for biomass-related traits, with moderate to strong gains across weights.

Reduced days to heading and moderate plant height are crucial in semiarid environments, ensuring synchronization with water availability and minimizing lodging risk (Fellahi et al., 2023). The Mulamba & Mock index effectively shortened heading time, aligning with the results of Guimarães et al. (2021), who found that this index is efficient in managing early maturity traits in rice (*Oryza sativa* L.). Biomass-related traits benefited from the Smith & Hazel and Cruz indices, both prioritizing plant structure and productivity, as also observed by Hannachi & Fellahi (2023) for durum wheat.

Chlorophyll content and flag leaf area, essential for photosynthesis efficiency under water stress, were best improved by the Mulamba & Mock index weighted by the variation index and by the Cruz index by h^2_{bs}, respectively. In this line, Peixoto et al. (2021) found that the Mulamba & Mock and Smith & Hazel indices optimized physiological and agronomic traits in biofortified lettuce. The Smith & Hazel, Mulamba & Mock, and Pesek & Baker indices also performed well in the present work for spike and kernel traits, in alignment with Meier et al. (2019), who reported similar patterns in wheat.

Overall, the Smith & Hazel, Mulamba & Mock, and Williams indices emerged as the most efficient for improving productivity and biomass-related traits in durum wheat. However, other studies have confirmed the versatility of several of the evaluated indices across different crops. For example: in soybean (*Glycine max* L.), the Williams index led to broad genetic gains (Bizari et al., 2017); in sugarcane (*Saccharum* spp.), the Mulamba & Mock and Pesek & Baker indices effectively selected for fiber and sucrose content (Azeredo et al., 2017); and, in maize, the Smith & Hazel and Mulamba & Mock indices improved grain and ear traits (Candido et al., 2020).

The coincidence analysis revealed an overlap of variables among the selection indices (Figure 2). There was a strong agreement, approaching 100% coincidence, between the Smith & Hazel index weighted by the CV_g and W1, as well as between the Pesek & Baker index calibrated by the CV_g and SD_g. These pairs consistently selected similar genotypes: G10, G12, G42, G4, G18, and G11 by the Smith & Hazel index weighted by CV_g and W1; and G42, G14, G4, G55, G56, and G2 by the Pesek & Baker index by CV_g and SD_g. These results are an indicative of similar weighting patterns among traits.

There was a partial overlap, i.e., a moderate coincidence of ≈81.5%, between the Mulamba & Mock index weighted by the CV_g and W1, reflecting slight differences in trait emphasis. In contrast, low or negative coincidence values of -11.1% were found between the Smith & Hazel and Mulamba & Mock indices weighted by the variation index, suggesting divergent selection criteria, with each index prioritizing distinct trait groups.

Across all indices, genotypes G42, G4, G10, and G12 were repeatedly selected, with G42 appearing in nearly every index, highlighting its adaptability and superior multi-trait performance. These findings support the relevance of coincidence-based multi-index selection for identifying genotypes with balanced agronomic and physiological traits, as confirmed by Meier et al. (2021) and Sellami et al. (2024), who found that multi-index selection enhances overall genetic gain and yield stability across environments. However, as the present study was conducted in a single environment, further multi-location and multi-year trials are needed

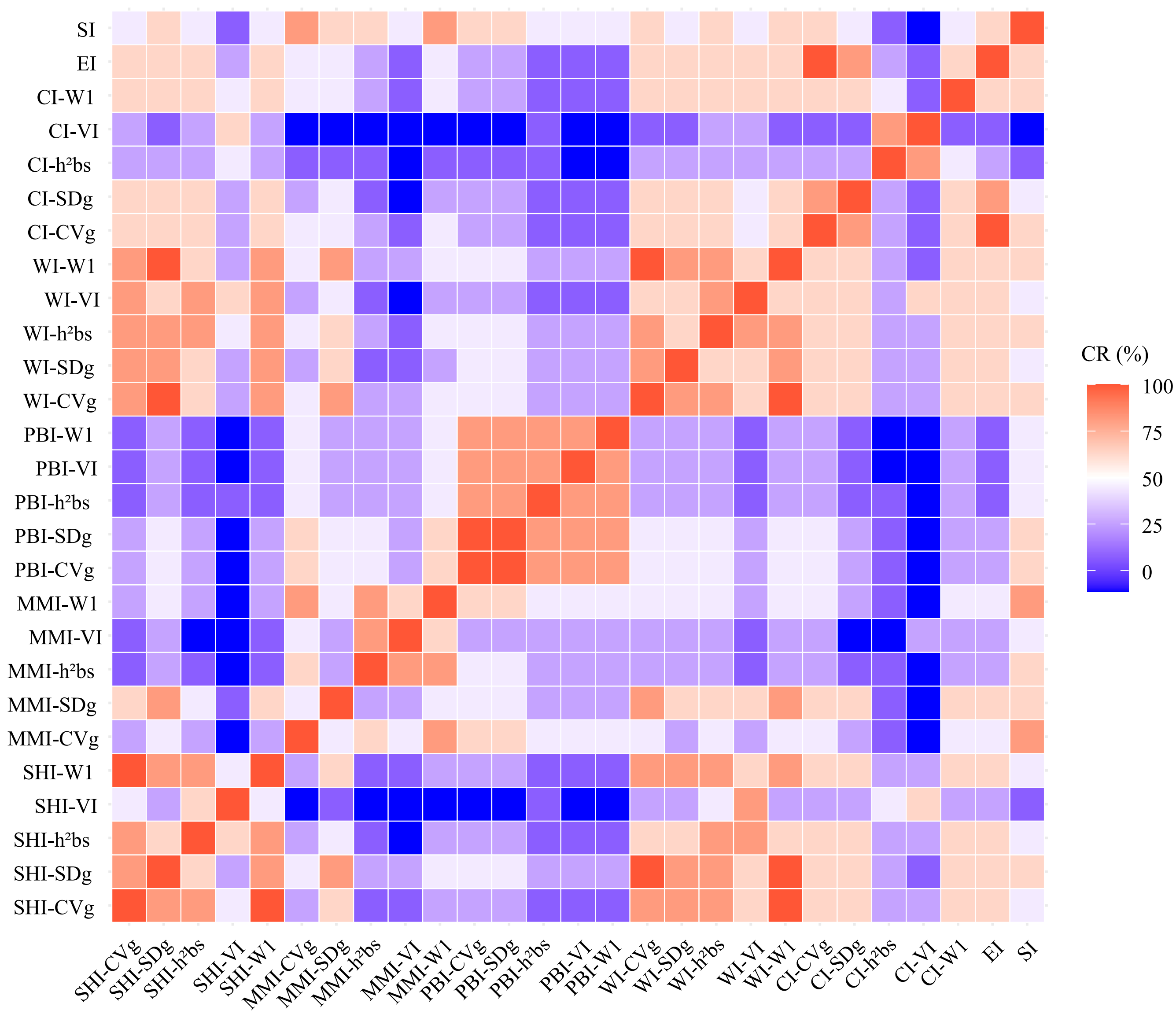

Figure 2. Heatmap of coincidence rates (CR) between selection indices. SI, Subandi index; EI, Elston index; CI, Cruz index; WI, Williams index; PBI, Pesek & Baker index; MMI, Mulamba & Mock index; SHI, Smith & Hazel index; W1, economic weight equal to 1; VI, variation index; h^2_{bs}, broad-sense heritability; SD_g, genetic standard deviation; and CV_g, genetic coefficient of variation.

to confirm the stability and adaptability of the selected genotypes.

Conclusions

1. Durum wheat (*Triticum durum*) genotypes show a substantial genetic variability under semiarid conditions, with a high heritability for days to heading, plant height, chlorophyll content, and straw yield, indicating a strong potential for selection.

2. The Mulamba & Mock and Smith & Hazel indices weighted by heritability and the variation index lead to the most balanced genetic gains across key agronomic traits.

3. Index-based selection proves effective for multi-trait improvement, supporting its use in durum wheat breeding programs.

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Author contributions

Abou-bakr Rabti: conceptualization (equal), data curation (equal), formal analysis (equal), investigation (equal), methodology (equal), project administration (equal), resources (equal), software (supporting), supervision (equal), validation (equal), visualization (equal), writing - original draft (equal), writing - review & editing (equal); **Zine El Abidine Fellahi**: conceptualization (equal), data curation (equal), formal analysis (equal), investigation (equal), methodology (equal), project administration (equal), resources (equal), software (lead), supervision (equal), validation (equal), visualization (equal), writing - original draft (equal), writing - review & editing (equal).

Chief editor: Edemar Corazza
Edited by: Madalena Rinaldi

Data availability statement

Data available upon request: The research data supporting the findings of this study are available from the corresponding author upon reasonable request.

Declaration of use of AI technologies

No generative artificial intelligence (AI) was used in this study.

Conflict of interest statement

The authors declare no conflicts of interest.

Acknowledgments

To the personnel of the agricultural experimental station of Institut Technique des Grandes Cultures in Sétif, Algeria (ITGC-AES Sétif), for their valuable assistance in setting up the experiment.