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Morpho-anatomical characteristics associated with lodging resistance in local and imported bread wheat

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Abstract

Wheat (*Triticum aestivum* L.) production is very limited by lodging, which negatively affects grain yield and quality. Lodging resistance is a complex trait determined by the combined effects of anatomical and morphology stem characteristics influencing stem strength and flexibility. Enhanced resistance is associated with increased development of supportive tissues (sclerenchyma and collenchyma), reduced structural weaknesses such as smaller pith cavities, and greater structural efficiency reflected by higher vascular bundle density. An optimal plant architecture is therefore defined by structural balance, including moderate plant height and regulated branching, rather than extreme dwarfism or excessive tillering. this study examined critical structural, morphological and anatomical characteristics traits of the wheat stem across fifteen wheat genotypes were evaluated using a randomized complete block design method. Significant varietal differences were found in the results, with genotypes showing stronger resistance to lodging having thicker sclerenchyma and collenchyma layers, smaller pith cavities, and higher vascular bundle densities such as in varaiety among the evaluated varieties, Hawler2, Hawler4, Slemani2, Azmar, Dink, Koya18, Maarof, and Monaliza exhibited superior performance compared with the other tested varieties. morphological characteristics like balanced tiller density and moderate plant height and widest stem diameter Varieties such as Arabea, Hawler2, Slemani2, Azmar, Koya18, Bakrajo, and Monaliza showed better performance than the other varieties. The combination of morphological and anatomical tests reveals the intricate mechanisms that wheat cultivators use to resist mechanical stress. For breeding efforts looking to combine increased rigidity with high yield potential, these findings offer insightful information.

Keywords: Wheat, Lodging resistance, sclerenchyma, morphological traits, Vascular bundles

Introduction

Lodging in grain crops causes substantial economic losses due to reduced yields, grain quality, and harvesting efficiency. Previous research revealed an important relationship between lodging resistance and some morphological and anatomical traits [1-3]. Solid stemmed wheat (*Triticum aestivum L.*), has thin, extremely rigid stems with solid materials stored inside the pith. Solid-stemmed wheat's morphology characteristics suggest it may be extremely resistant to lodging. According to [4] the genetic traits of the parental plants and/or the way the research was conducted determined whether the solid stem hereditary traits of durum wheat (*Tritium durum Desf.*, 2n = 4x = 28) were simple, dominant, recessive, or complicated.

Furthermore, an F2 generation resulting from a hybrid between a solid-stemmed and a hollow-stemmed variety was used to identify the gene or genes determining stem solidity. Lodging resistance is correlated with anatomical characteristics such the thickness of the Culm wall, the number of vascular bundles, the diameter of the Culm cavity and vascular bundles, and the thickness between the sclerenchyma layer and the epidermis [5], [10]. Importantly, dwarfing genes produce shorter plants, which lowers the plant's center of gravity and lessens the leverage forces operating on it. This behavioral manifestation of stem strength is achieved.

Additionally, the stem's resistance to buckling is greatly enhance by a higher biomass density, a greater amount of structural elements like lignin, and a larger stem wall diameter, especially in the crucial basal internodes [3]. A large amount of research indicates that the second internodes' properties are crucial for estimating stem lodging in wheat [19], [22]. Stem strength is strongly influenced by the length, diameter, wall thickness, density, and component composition.

By strengthening the stem, choosing a wider stem diameter and thicker wall can help wheat resist lodging [13]. Enhancing the thickness of the secondary cell wall in wheat stems may improve grain support by increasing stem mass and structural strength. Nevertheless, excessive wall thickening can add unnecessary weight, which may elevate mechanical stress and increase susceptibility to lodging [6]. The purpose of this study was to further our knowledge of the connection between the behavioral and anatomical characteristics of stems in various wheat cultivars and how they affect lodging resistance.

Materials and Methods

This study will be carried out at the Tarjan field, situated 33 km from the center of Hawler within a moderate rainfall region. The fifteen bread wheat varieties used in the study are listed in (Table 1). The experiment was conducted on December 6, 2024, at an experiment location with coordinates of 22° longitudes, 8° latitudes, and a surface area of 176 meters. The meteorological data of Tarjan location is shown in

(Table 2). Each variety will be sown in a plot measuring 2m² (2m x 1m), with a spacing of 0.2 meters between rows and 0.2 meters between plants within each row. The plants will receive supplementary irrigation as needed and will be fertilized with NP 20:20 fertilizer. The experiment will be arranged in a Randomized Complete Block Design (RCBD) 15 samples with three replications (15 × 3=45).

Table (1): The pedigree of the genotypes.

Number	Variety name	Pedigree
1	Arabea	Certified varieties / Import / Dabana company
2	Hawler-2	Florkwa2/6/Sakers/5//YMH/TOB/4/BOWS-LC96-0180-030APS-2AP-DAPS-OPA
3	Hawler-4	Baj#1/3/KirijAI/A*2/Pastor CMSSOYOO288S-OS8-099Y-99M-099Y3M-OWGY
4	Slimani-2	KAUZ*2/YACO//KAUZ/3/OA-SIS/2*BORL95 CMSS97M05852S-020Y-030M-202Y-040M-14Y-2M-0Y
5	Azmar	CMH 83/ ELVIRA// CMH 79/ AGA/ INIA (Rad.)
6	Koya-4	PASTOR/3/KAUZX2/KAUZ//ALTRA84AOS Selection history: KARS09-02-0KO-0KO-0KO-29KO-36KO
7	Koya-18	BHRIKUTI NL623/KAUZ//AL-TRA84AOS Selection history: KARS09-05-0KO-0KO-0KO-136KO-28KO
8	Bakrajo	Sup152/BAJ#1/4BAJ#1/3KIRITATI//AT-TILA*2/PASTOR/5/ CMSS12Y00919T-099TOPM-099Y-099M-OSY-13M-OWGY
9	Tamuz-2	Sab./Max. (Rad.)
10	Jihan	Certifies varieties / Import / Entry approved by the Ministry of Agriculture
11	Aras	Sentaelena*(Sonara64*Lerma Rojo64)
12	Rzgare	Certified varieties /Erbil - Agriculture research center
13	Dink	Certified varieties / Al-Rif Gazraa company/ Kauz*Pastor
14	Monaliza	Certifies varieties / import
15	Maaruf	KTN M12/DAMAN × ADL//TAMUZ 2

Table (2): Monthly rainfall and average air temperature from November 2024 to June 2025

Months and years	Rainfall (mm)	Average air temperature (c°)
2024,November	9.2	16.3
2024,December	15.8	11.0
2025,January	58.3	10.8
2025,February	35.5	9.5
2025,March	25.6	17.7
2025,April	16.3	24.3
2025,May	4.5	30.0
2025,June	0	35.4

Traits studied

Plant collection for morphological

Data were collected from the 15 genotypes evaluated for morphological traits. Fifteen individual plants taken at random from the harvest area of each plot were used as samples.

Morphological Traits

1- Plant height (cm) [17], Stem diameter (mm) [19], Number of tillers (m^{-2}) [2], Number of spikes ($spike.m^{-2}$) [2], Number of grains per spike ($grain.\ Spike^{-1}$) [2], Spike length (cm) [2], Grain yield ($ton.\ ha^{-1}$) [2], Thousand-grain yield (g) [16], Biological Yield ($ton.\ ha^{-1}$) [14].

Plant collection for anatomical

Plant parts of stem were taken on plants at a milk growth stage within Tarjan field, date of sampling at (2025/11/5) and kept in small vial containing FAA solution and labeled, the following steps were taken to prepare permanent slides for stem cross sections as applied by [8]. Killing and Fixation [15], washing and Dehydration, clearing and Infiltration, embedding and mounting, deparaffinizing and staining, permanent Mounting.

Statistical Analysis:

All recorded data are examined using analysis of variance (ANOVA). The collected data are subjected to statistical analysis utilizing SAS software, and Duncan’s Multiple Range Test is used for mean comparison at the 0.05 level of significance.

Results and Discussion

The results of this study showed the morphology of fifteen wheat varieties (*Triticum aestivum L.*). Most of them differed significantly in the studied traits, as presented in Table (3). Variety Hawler-4 showed the maximum value for days to 75% maturity (163.66 days). While Tamuz2 variety recorded the minimum value (148.33 days) and varied significantly. the earliest maturity was superior, because it reduces the plant's exposure to external pressures and is frequently associated with shorter, stronger stems, early maturity is a crucial characteristic for lowering the danger of lodging.

This discovery points to a viable option for enhancing lodging resistance in breeding projects. Additionally, Table (3) Indicated that a significant difference was observed among plant height. Variety Maarof showed the highest value for plant height (95.33cm). While the Hawler-2 variety recorded the lowest plant height reached (79.76cm). This confirms that reduced plant height enhances stem stability and lowers lodging risk, supporting yield protection. Also, stem diameter had significant effects on lodging resistance; Koya-4 had the thickest stem (0.41 mm), indicating higher strength. By improving stalk stability and wind resistance, thicker stems lower the likelihood of lodging by offering more mechanical support and resistance to bending, it means lodging resistance is impacted by the ratio of wall thickness to pith diameter, with thicker walls and smaller pith providing greater strength of the stem.

On the other hand, statistical analysis indicated significant differences among the varieties in tiller number, which ranged from 523.3 in Maarof to 850.0 in Tamuz-2, and in spike number which ranged from 463.33 in Maarof to 826.67 in Tamuz-2, the number of spike may be influenced by the number of vascular bundles since more bundles can sustain a greater number of spikes via improving nutrition and water delivery. the number of spike A positive relationship between these traits could improve both stem function and yield potential.

Additionally, information on the density of tillers and spikes per square meter gives sunlight on the design of the canopy. A competitive microenvironment produced by too high densities may result in weaker stems and a higher risk of lodging. Furthermore, the number of grains per spike varied from 42.76 Aras to 56.86 Monaliza, with higher-grain varieties showing greater yield potential but increased lodging susceptibility, if it is not supported by a strong stalk, moderate grain numbers provided a balance between productivity and stem stability, reducing the risk of lodging.

In addition, Spike length affects lodging, the shortest spike lengths of 8.43 cm are found in varieties such as Dink and Monaliza. Shorter spike increase resistance, while longer spikes increase the weight at the top and increase the chance of stem bending [3, 9]. The Maximum wheat biological yield (34.86 Tamuz-2) indicates high lodging risk due to greater stem load, While the minimum biological yeild (21.60 Hawler-4) suggests better inherent resistance. This illustrates the critical trade-off between maximizing productivity and maintaining structural stability in crops.

Table (3): Performance of morphological related traits of 15 different bread wheat (*Triticum aestivum* L.) varieties

Varieties	days to 75% flowering (day)	days to 75% maturity (day)	Plant height (cm)	Stem diameter (mm)	Number of tillers.m^{-2}	Number of spikes. m^{-2}	Number of grains per spike	Spike length (cm)	Grain yield (ton.ha^{-1})	Thousand grain yield (g)	Biological yield (ton.ha^{-1})
Arabia	122.66^{c}	154.00^{ab}	91.16^{abc}	0.38^{ab}	540.0^{c}	531.67^{cd}	49.23^{ab}	10.23^{ab}	9.28^{cd}	39.20^{a}	23.43^{b}
Hawler-2	130.00^{ab}	158.66^{a}	79.76^{c}	0.37^{ab}	710.0^{abc}	693.33^{abc}	50.36^{ab}	8.66^{c}	11.36^{abc}	37.56^{a}	27.36^{ab}
Hawler-4	130.00^{ab}	163.66^{a}	92.30^{ab}	0.37^{ab}	540.0^{c}	528.67cd	47.43^{ab}	9.66^{abc}	8.79^{cd}	42.83^{a}	21.60^{b}
Slemani2	124.00^{c}	155.66^{ab}	85.63^{abc}	0.35^{ab}	666.7^{abc}	661.67^{abcd}	47.66^{ab}	9.46^{abc}	8.70^{cd}	34.93^{a}	29.33^{ab}
Azmar	130.66^{a}	160.66^{a}	85.06^{abc}	0.37^{ab}	630.0^{abc}	616.67^{abcd}	44.23^{b}	10.20^{ab}	12.65^{ab}	37.03^{a}	24.86^{ab}
Koya4	130.33^{ab}	160.33^{a}	89.76^{abc}	0.41^{a}	580.0^{bc}	566.67^{bcd}	46.50^{ab}	9.33^{abc}	9.26^{cd}	40.00^{a}	28.10^{ab}
Koya18	129.00^{ab}	158.66^{a}	81.86^{bc}	0.38^{ab}	603.3^{bc}	596.67^{bcd}	50.00^{ab}	9.60^{abc}	9.81^{bcd}	35.06^{a}	25.73^{ab}
Bakra jo	127.33^{b}	160.33^{a}	85.16^{abc}	0.37^{ab}	746.7^{abc}	730.00^{abc}	42.93^{b}	9.63^{abc}	9.74^{bcd}	40.96^{a}	28.56^{ab}
Tamuz-2	130.66^{a}	148.33^{b}	87.50^{abc}	0.32^{b}	850.0^{a}	826.67^{a}	48.66^{ab}	10.46^{a}	10.52^{abcd}	36.06^{a}	34.86a
jihan	128.00^{ab}	159.66^{a}	88.13^{abc}	0.34^{b}	796.7^{ab}	766.67^{ab}	45.86^{b}	9.70^{abc}	10.52^{abcd}	37.70^{a}	31.60^{ab}
Aras	128.66^{ab}	161.00^{a}	90.24^{abc}	0.32^{b}	740.0^{abc}	726.67^{abc}	42.76^{b}	9.46^{abc}	13.08^{a}	39.80^{a}	31.73^{ab}
Rzgari	130.33^{ab}	161.00^{a}	93.03^{ab}	0.35^{ab}	693.3^{abc}	686.67^{abc}	50.40^{ab}	10.20^{ab}	7.85^{d}	32.50^{a}	24.00^{ab}
Dink	129.00^{ab}	157.66^{ab}	87.63^{abc}	0.35^{ab}	736.7^{abc}	733.67^{abc}	50.60^{ab}	8.43^{c}	9.79^{bcd}	40.03^{a}	29.13^{ab}
Monaliza	129.33^{ab}	161.66^{a}	85.03^{abc}	0.35^{ab}	673.3^{abc}	656.67^{abcd}	56.86^{a}	8.43^{c}	11.95^{abc}	35.83^{a}	27.80^{ab}
Maarof	128.66^{ab}	160.00^{a}	95.33^{a}	0.33^{b}	523.3^{c}	463.33^{d}	51.23^{ab}	9.86^{abc}	7.81^{d}	37.66^{a}	25.00^{ab}

Different letters after mean values in the same Column represent significant differences at P≤0.05.

Table 4 shows the results of stem anatomical traits of 15 bread wheat varsities. Stem strength is essential for preventing lodging, which is the permanent bending of stems from their upright posture and a significant contributor to grain production loss [3]. Key structural elements that contribute to this strength can be evaluated using the data in Table (4). Significant differences were also detected in the anatomical characteristics of the fifteen genotypes. One of the principal findings of this study was the identification of two predominant stem cross-sectional forms among the evaluated varieties, namely circular to sub-circular and oblong shapes (Figure 1). Circular or sub-circular stem cross sections, observed in varieties such as (Hawler-2, Hawler-4, Araz, Maarof, Arabea, Slemani-2 and Koya-18) are commonly reported in herbaceous plants and are associated with uniform resistance to mechanical stresses applied from multiple directions [12].

In contrast, oblong stem cross sections, recorded in varieties including (Bakrajo, Monaliza, Koya- 4, Dink, Rzgari, Tamuz-2, and Jihan and Aras). May reflect differences in growth habit or adaptive flexibility. Such structural variation could influence the spatial distribution of supportive tissues and alter the stem’s mechanical response to wind loading, potentially affecting lodging behavior. The positive relationship between stem rigidity and the quantity of vascular bundles is a secondary finding. Many of these structures are present in varieties like Monaliza (70 bundles) and Araz (68 bundles). The stem's mechanical strength and resistance to bending pressures are greatly increased by the reinforcing rod-like function of vascular bundles, which are made of fibrous sclerenchyma tissue [7], [12]. This implies that Araz and Monaliza might have a structural edge. On the other hand, cultivars with fewer of these supporting features, such as Jihan and Arabea (both of which have 44 bundles), can be more prone to buckling under stress. Another crucial element is the growth of sclerenchyma tissue, which serves as the stem's primary structural support. The results indicate significant heterogeneity in sclerenchyma cell width and length.

For example, Bakrajo has some of the broadest cells (117.31 µm) despite having a moderate number of sclerenchyma rows (9–10). Greater stem stiffness and resistance to snapping are attributed to the thicker cell walls of sclerenchyma cells that are longer and wider [11], [24]. Monaliza, on the other hand, has the shortest sclerenchyma cells (88.21 µm), which may indicate a compensatory deficit in its overall stem strength while having a high vascular bundle count. A direct indicator of stem solidity is the thickness of the stem wall itself. Because a larger cross- sectional area offers better resistance to bending forces, Araz's thickest stem wall (1168.39 µm) acts as a powerful barrier against lodging [20], [17]. Its modest hollow cavity pith diameter (166.38 µm) complements this, giving it a high solid wall to hollow space ratio- a crucial trait of genotypes that are resistant to lodging. On the other end of the spectrum, Maarof has the thinnest stem wall (485.09 µm) and a sizable hollow cavity, which together probably make it more susceptible to stem failure. It is important to consider the peripheral collenchyma tissue's function. Because of the flexible support provided by this tissue, the stem can wobble without breaking. Bakrajo may be more flexible and resilient to wind-induced oscillations since it has the thickest collenchyma (222.16 µm). Tamuz-2 and Maarof, with the thinnest collenchyma (122.32 µm and 92.69 µm, respectively), may lack sufficient elastic support, making their stems more brittle. Overall, the combined findings show that vascular bundle density, sclerenchyma and collenchyma growth stem wall thickness, and pith cavity dimensions all work together to determine lodging resistance rather than a single anatomical characteristic.

Araz, Hawler-2, and Hawler-4 are among the varieties that exhibit the best combinations of these characteristics, indicating that they might be hardier in the field. These results support the idea that in order to preserve crop stability and production potential, breeding for lodging resistance necessitates the simultaneous improvement of several stem structural traits [23]. Some Magnified Portions of the stem of studied *triticum aestivum* associated lodging Figure (2).

Table (4): Stem anatomical traits of 15 different bread wheat (*Triticum aestivum* L.) varieties

Varieties	Stem outline shape	Number of vascular bundle	Number of sclerenchyma rows	Length of sclerenchyma	Width of sclerenchyma	Number of layers of collenchyma	Thickness of collenchyma	Thickness of stem wall	Hollow cavity pith diameter	Area of vascular bundle
Arabea	Sub- circular	44	7 to 9	157.89	64.96	3-6	172.392	761.74	565.23	139.77
Hawler-2	circular	51	8 to 10	159.63	68.28	5-7	156.579	676.99	501.53	227.29
Hawler-4	circular	53	8 to 9	160.10	107.81	3-6	141.81	685.23	524.61	159.58
Slemani-2	Sub-circular	53	9 to 11	149.28	45.25	3-6	191.65	760.31	390.08	154.04
Azmar	circular	46	8 to 8	154.09	92.34	2-6	160.09	912.23	412.79	164.22
Koya-4	oblong	51	8 to 9	148.40	108.50	5-7	178.08	652.89	720.98	163.45
Koya18	Sub- circular	52	9 to 11	143.16	78.41	3-6	149.75	825.49	456.71	174.92
Bakrajo	oblong	49	9 to 10	120.93	117.31	4-6	222.16	850.47	585.21	170.72
Tamuz-2	oblong	52	7 to 8	96.19	91.67	2-6	122.32	572.24	584.45	160.00
jihan	oblong	44	7 to 8	113.94	70.20	4-7	158.29	904.46	264.84	147.44
Araz	circular	68	8 to 10	133.53	85.73	5-7	114.99	1168.39	166.38	158.17
Rzgari	oblong	54	8 to 9	135.88	77.71	3-5	176.79	657.48	612.48	149.43
Dink	oblong	52	7 to 9	123.99	108.46	3-7 s	161.09	759.47	321.71	166.03
Monaliza	oblong	70	6 to 8	88.21	92.87	3-6	116.34	607.24	632.32	159.20
Maarof	circular	62	6 to 7	115.18	131.66	2-4	92.69	485.09	558.18	165.65

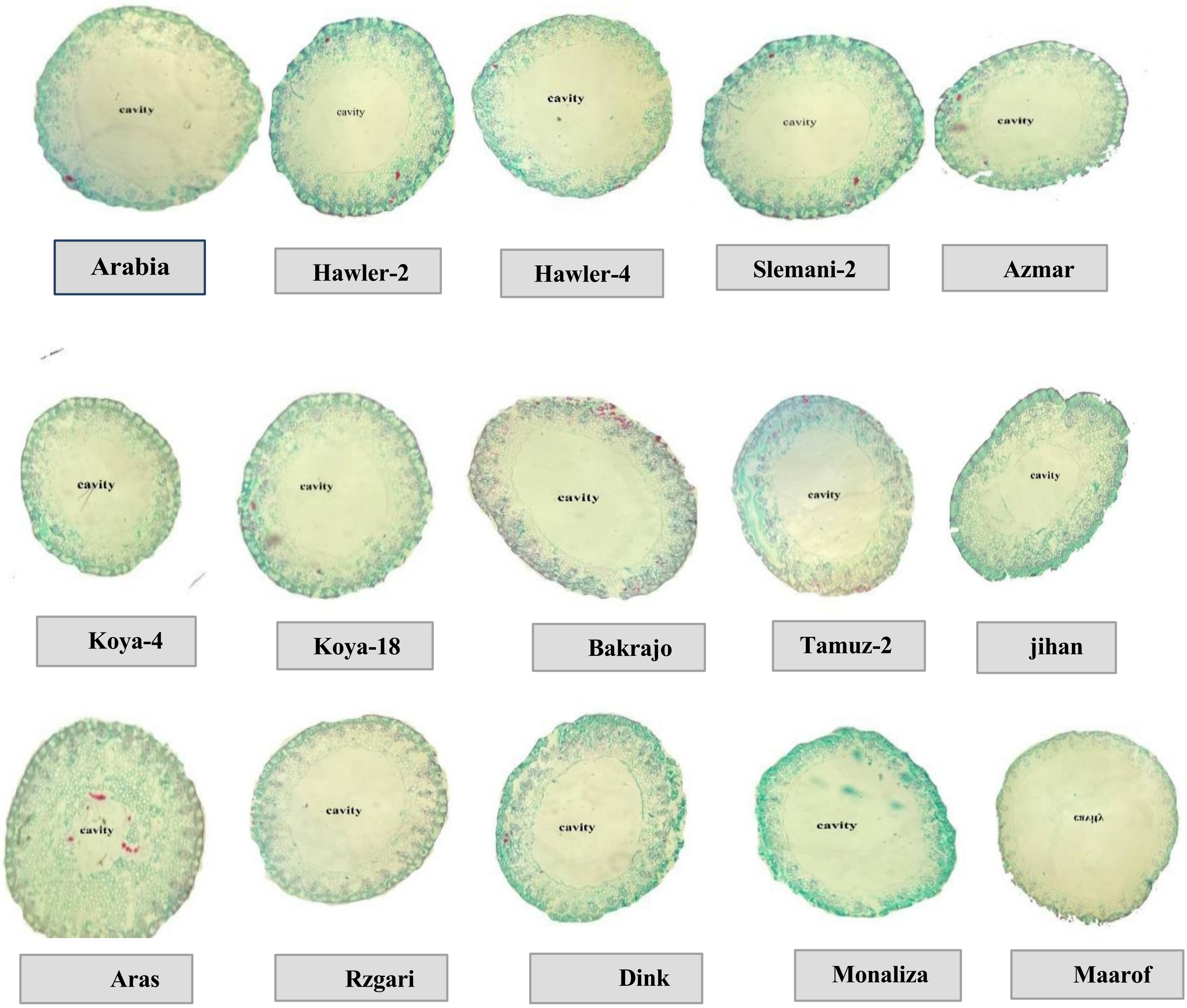

Figure (1): Stem cross-sections of 15 bread wheat varieties (4X)

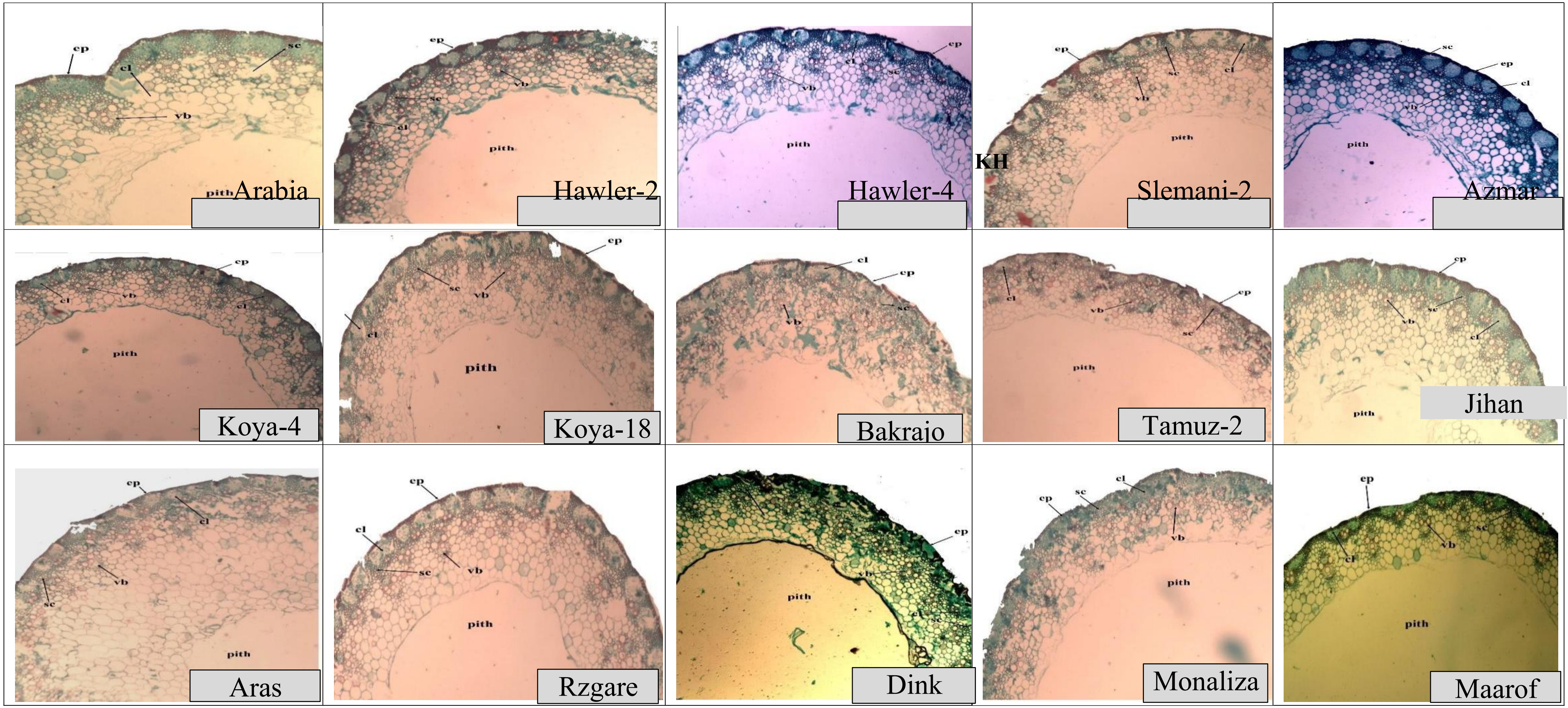

Figure (2): Magnified Portions of the stem of studied *triticum aestivum* associated lodging (4X), ep: epidermis, sc: sclerenchyma, v.b: vascular bundle, cl: collenchyma.

Conclusion:

The results showed significant morphological variation among the fifteen bread wheat varieties. Differences were visible in morphological traits, plant height, stem diameter, tiller and spike density, grain number per spike and yield performance, demonstrating significant variation among the genotypes under study. Wheat varieties displaying with moderate plant height, suitable stem diameter, and adequate tiller and spike densities are anticipated to have improved mechanical stability. High tiller or spike densities may make a canopy heavier and more prone to lodging, while low densities may jeopardize stand support These results give a strong basis for choosing superior wheat varieties for breeding efforts targeted at improving stem strength, stability, and yield performance. They also indicate that morphological features are crucial in predicting lodging resistance.

Significant differences in stem architecture among the specimens under study are highlighted by the anatomical data, most likely due to adaptations to various physiological or ecological demands. Thick sclerenchyma and collenchyma tissues, as well as circular and sub-circular stems, may improve transport efficiency and mechanical stability. and smaller hollow cavity widths, larger stem walls, and higher vascular bundle counts and area (e.g., Araz and Hawler2) have a higher potential for lodging resistance. On the other hand, larger cavity diameters like (Arabea) and lower vascular bundles may be more vulnerable to stem bending and breakage, whereas oblong forms and decreased sclerenchyma may suggest adaptations for flexibility or quick growth. In breeding projects designed to increase the strength of wheat stems, these characteristics can be helpful selection criteria.

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