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Research Article

INDIGENOUS CUCURBITS AND GRAFTING TECHNIQUES AFFECT CUCUMBER PRODUCTIVITY BY MODULATING MORPHO-PHYSIO-BIOCHEMICAL INDICES

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Abstract

Vegetable grafting is a unique surgical horticultural technology for inducing soilborne biotic and abiotic stress tolerance in cucumbers. Indigenous cucurbit germplasm as rootstocks may show more tolerance potential compared to exotic ones. However, it needs evaluation for compatibility testing through various grafting techniques. Therefore, this study was planned to test available cucurbits as rootstocks for graft success vis-à-vis cucumber growth and productivity. It was carried out in the Plant Propagation and Physiology lab at MNS University of Agriculture, Multan, Pakistan. The seeds of the indigenous open-pollinated cucurbits were sown in 64-celled plug trays with peat moss as growing media, followed by shifting to 50-celled plug trays at the first true leaf emergence stage. The seeds of selected scion (cucumber) were sown after the emergence of rootstock seeds. Different grafting techniques were performed at the first true leaf stage of the scion, followed by healing and acclimatization. In this experiment, hybrid cucumber (cv Yalla F1) was grafted on three indigenous cucurbits, namely ridge gourd (*Luffa acutangular*), bottle gourd (*Lagenaria sicearia*) and pumpkin (*Cucurbit pepo*. L) for graft compatibility success by using three grafting techniques: cleft grafting, one cotyledon grafting and hole insertion. Non-grafted cucumber was grown to compare with grafted plants for growth and productivity. Overall, significant ($p \leq 0.5\%$) results were obtained regarding a 90% survival rate in cucumber plants grafted onto the bottle gourd through cleft grafting compared to the other grafting techniques. Additionally, the cucumber plants grafted on bottle gourd showed the highest morphological (root length, shoot length, root fresh weight, shoot fresh weight and rootstocks, and scion gir th), physiological (photosynthetic rate, transpiration rate, stomatal conductance, and sub-stomatal conductance), biochemical (antioxidants activities, SOD, CAT, and POX) and yield indices (average fruit length, weight, numbers, and yield) as compared to the non-grafted plants. Conclusively, cucumber grafting onto indigenous bottle gourd with cleft grafting technique exhibited maximum compatibility confirmed through physio-chemical attributes and improved plant biomass and yield, thereby suggested for cucumber grafting.

Keywords: *Cucumber, Grafting Technique, Rootstock, Scion, Abiotic Stress, Biotic Stress*
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1. INTRODUCTION

Cucumber (Cucumis sativus L) is a precious, nutritious, and commonly consumed vegetable (Ziaf et al., 2021; Gish and Gikalo, 2012). Globally, 1.17 billion tonnes of vegetables are produced (FAO 2023), while 4.6 million tons are produced in Pakistan (Talpur et al., 2022) to fulfil the requirements of the increasing population. However, vegetable crop production in Pakistan is less as compared to other growing countries due to various biotic (soilborne disease) and abiotic stresses (salinity, drought, and temperature extremes) (Nawaz et al., 2017). There are different ways to increase the economic and nutritional values of the crops through bio-fumigation (Gilardi et al., 2014), crop rotation (Lee et al., 2010), using resistant verities and vegetable grafting (Nawaz et al., 2016). Vegetable grafting may improve cucumber productivity, thereby increasing farmer profitability through managing the soilborne challenges and improving crop output while lowering the cost of purchasing higher quantities of fertilizers and chemicals (AARI, 2017). Vegetable grafting is practiced in Cucurbitaceae (cucumber, watermelon) and Solanaceae (tomato and peppers) crops (Bie et al., 2017). It has become a technique with a high potential to improve the efficiency of modern and intellectual vegetable cultivation and indicates adoptability and resistance under different stress situations (Kumar et al., 2017). The grafted watermelon has successfully grown for sustainable production in most countries, such as Spain, Italy, Japan, and Korea (Bantis et al., 2021). Also, tomatoes, cucumbers, and eggplant grafting are being adopted worldwide. Under low or no disease pressure, the plant's growth and productivity can be improved considerably when vigorous rootstocks are used along-with maximum water and nutrient use efficiency (Martínez-Ballesta et al., 2010). Grafting has a significant role in enhancing plant biomass parameters(Cuevas et al., 2019) in many crops including cucumber (Amaro et al., 2014; Noor et al., 2019; Usanmaz and Abak, 2019), brinjal (Ulas, 2021), melon (Ulas et al., 2019), pepper (Soltan et al., 2017; Abdelaal et al., 2020; Padilla et al., 2021), tomato (Mauro et al., 2020; Parthasarathi et al., 2021) and watermelon (Huang et al., 2016b; Yanyan et al., 2018). Grafting also improves gas exchange traits i.e., stomatal and sub-stomatal conductance, photosynthetic rate and WUE. Similarly, yield is an important parameter. Many researchers have concluded that grafted plants can induce tolerance against stresses and help maintain higher crop productivity (Sandoval et al., 2007; Yang et al., 2015; Uttekar et al., 2021; Kuşvuran et al., 2021, Liang et al., 2021).

Moreover, grafting process involves selection of rootstock and scion cultivars, plantlet production, grafting operation (creation of physical union) as per the stem girths and growth pattern, healing of graft union, and acclimatization of grafted transplants for the production of success grafted transplants (Bie et al., 2017). The healing of the grafted union is an energy-consumption process. During the structural and biological development of graft healing, three primary phases are accomplished: combining scion and rootstock, callus creation around the joint, and establishing continuity at the joint through vascular re-differentiation(Melnyk, 2017). Similarly, sugar is an essential activator for the homograft union's elongation and cell division processes (Melnyk et al., 2018). The high concentration of exogenous glucose reduces the efficiency of the graft.

In contrast, low concentration has no significant effects on the graft's survival rate but improves grafted plants' growth during healing. the Root growth occurs during graft formation after the phloem and xylem connection. A lower supply of sugar is maintained in the rootstock and scion during graft union development, which plays a vital role in the vascular connection and grafted plant growth (Miao et al., 2021).

The grafting method depends on crop type (rootstock-scion stem girth), budder (grower) experience and available facilities because vascular connection formation is an essential and critical stage during would healing as well as solute and water transport from rootstock to scion (Moore, 1984; Velasco Alvarado, 2013). Different grafting methods like hole insertion, tongue approach, splice/ cleft, and pin grafting are adopted in vegetables for maximum success of grafted plants that depend on rootstock and scion girth along-with collar diameter

(Lee et al., 1998; Lee et al., 2010). Nowadays, mechanical grafting, including robots, is being introduced to perform grafting operations in Korea, Japan, the Netherlands, Spain, and the USA (Bie et al., 2017). The grafting technique exhibits positive responses, including stress tolerance, growth, and productivity enhancement (Oda, 2002; Lee and Oda, 2002). Cucumber grafting on various rootstocks and techniques decreases precocity but enhances overall yield relative to non-grafted. The grafting technique is pivotal in vascular reconnection (a key event in graft healing), particularly in cucurbits due to ∼1000 species(Guo et al., 2020; Melnyk, 2017). If incompatibility exists, it leads to graft failure due to necrotic layer development and non-differentiation of vascular bundle, hence issues in bidirectional hormones, nutrients, water and photosynthates transport (Xu et al., 2012; Camalle et al., 2021).

In this regard, an earthen pot (9-inch) based study was planned to investigate the effect of different grafting techniques on the graft compatibility of cucumber F1 when grafted onto different indigenous cucurbits under lab and lath house growing conditions. The hybrid scion cucumber (cv Yalla F1) and four indigenous cucurbits, namely ridge gourd (Luffa operculate L.), pumpkin (Cucurbita pepo L.), bottle gourd (Lagenaria siceraria L.) and non-grafted were used as scion-rootstock combinations to check the compatibility through cleft, single cotyledon and hole insertion grafting methods.

2. MATERIALS AND METHODS

2.1. Site and location

This experiment was carried out in the plant propagation and physiology laboratory (nursery development, grafting, and healing) followed by transplanting of the grafted plants in earthen pots in lath house MNS University of Agriculture Multan, Pakistan (longitude *71°26'35.43"E* and Latitude *31° 8'26.93" N*) using Complete Randomized Design (CRD) with three replications and two factors factorial design arrangements.

2.2. Seedling Production and Grafting

In this experiment, three indigenous cucurbit landraces, ridge gourd, pumpkin, and bottle gourd, were used like cucurbits rootstock while cucumber (cv Yalla F1) was used as a scion on the mentioned cucurbits. In this experiment, the seeds were sown in 128-celled plug trays, then shifted to 50-celled plug trays at the emergence of true leaves of rootstocks by using peat moss as growing media, followed by grafting. Imported peat moss (https://www.agaris.com/en/products) was used for healthy vegetable seedling development. After about 25 days, grafting was done by using the three-grafting technique (cleft, single cotyledon, and hole insertion grafting) followed by shifting to a healing chamber containing temperature and relative humidity (R.H.) of 21-23℃ and 90-95%, respectively for a period of first four days followed by a reduction in R.H. (75%) to acclimatize the plants. Later, the acclimatized grafted plants were shifted to earthen pots containing growing media of silt, garden soil, and FYM in a 1:1:1 ratio.

2.3. Grafting Methods

2.3.1. Cleft Grafting

This grafting technique removed true leaves, and a vertical cut was made at the center of two cotyledonary leaves. Then, the scion was cut in a wedge shape of the same size, inserted in the rootstock, and covered with a grafting clip (Johnson et al., 2011).

2.3.2. Single cotyledon Grating

In this technique, one cotyledonary leaf was removed from the growing point of rootstock. A slanting cut of the same size scion was made and inserted on the rootstock, then clipped carefully. This is the common method for cucurbit plants, also known as one cotyledon/single cotyledon splice grafting (Lee et al., 2010).

2.3.3. Hole Insertion Grafting

In this grafting technique, a hole is made with the help of a minor, narrow wooden stick at the growing point of the rootstocks after removing the actual leaves. A cut is made on both sides of the scion and inserted in the rootstock hole (Bletsos and Olympios, 2008).

2.3.4. Survival Rates

The survival rate of the grafted plants was investigated during healing, acclimatization, and after transplanting by the following formula (Traka-Mavrona et al., 2000):

$$\text{Survivals Rates} = \frac{number\ of\ survived\ grafted\ plant}{total\ number\ of\ grafted\ plants} \times 100$$

2.3.5. Parameters Studied

The data for the following parameters were collected to assess the compatibility of three indigenous cucurbit landraces with hybrid cucumber (cv Yalla F1) scion using three grafting techniques.

2.3.6. Morphological attributes

All morphological attributes, including shoot and root lengths internodal distance, were noted by measuring scale while root and shoot fresh weight and root and shoot dry weight were calculated with digital weighing balance. Besides, rootstocks and scion girth were determined by the vernier calliper.

2.3.7. Gaseous exchange attributes

The fully mature 3^{rd}-4^{th} plant leaves were selected for the collection of gaseous exchange attributes such as stomatal and sub-stomatal conductance, photosynthetic rate, transpiration rate and WUE by the P.P. System (Portable Photosynthetic System) (CIRAS-3 HANSTACK INSTRUMENT Ltd., Pentney, UK) (CIRAS-3, Hansatech Instruments Ltd., Pentney, UK). This system was operated from 10:00 a.m. to 3:00 p.m. at 900 $\mu mol \cdot m^{-2} \cdot s^{-1}$ photosynthetic photon flux concentration, 96.9 kPa atmospheric pressure, 100 $mL \cdot min^{-1}$ airflow rate, and 385 ± 5 $\mu mol \cdot mol \cdot CO_2$ concentration rates.

2.3.8. Bio-chemical attributes

The antioxidant scavenging activity (ASA) was measured by adopting the method of(Mimica-Dukić *et al.*, 2003). One gram of cucumber leaves was homogenized, 2 ml of phosphate buffer (pH 7.0), and centrifuged at 9000 rpm for 5 minutes at 4°C. About 50 µL supernatant and 5 ml DPPH (2,2-diphenyl-1- picryl-hydrazyl-hydrate) were incubated for 30 minutes and took 250 µL in microplates. Then, ASA was measured by the ELIZA reader (Epoch in Winooski, United States of America) at an absorbance of 517nm. Similarly, Superoxidase Dismutase was determined by following the method devised by). In this protocol, about 200 µL Titron X, 200 µL Methion, 200 µL Phosphate buffer (pH 5.0), 100 µL Nitro Blue tetrazolium, and 800 µL distilled water were dissolved in test tubes by adding the 100 µL supernatant followed by shifting test tubes under laminar flow hood for U.V. light treatment for 15 minutes. Later, 100 µL of riboflavin was added. 200 µL supernatant was added to the microplates and ran at the absorbance of 560nm through ELIZA. Similarly, the methods developed by Razzaq et al., (2013) determined total phenolic contents, catalase, and peroxidases. Catalase was determined by reaction mixture having the H_2O_2 100 µL along with enzyme extract 100 µL then absorbance at 240nm. Peroxidase was calculated by adding 20 mM guaiacol, H_2O_2 of 40 mM, phosphate buffer (pH 5.0), and 100 µL supernatant and absorbance at 470nm (Liu *et al.*, 2009). TPC was determined by adding 200 µL Folin Ciocalteu (F.C.), 100 µL supernatant and 800 µL Na_2CO_3 followed by addition of 200 µL from an above mixture in the microplates followed by running at the absorbance of 765 nm on the plate of ELIZA.

2.3.9. Yield related attributes

Yield-related attributes such as cucumber fruit length (cm), diameter (mm), average fruit weight, and fruit yield per plant were calculated by measuring tape, a vernier calliper and digital weighing balance, respectively.

2.4. Statistical Analysis

Statistically, the data was evaluated by Statistix 8.1 software (Tallahassee, Florida, USA) under a complete randomized design with three replications and 2-factor factorial arrangements. Tukey's (HSD) was used for interaction means correlation at the 5% ($P<0.05$) probability level.

3. Results

3.1. Morphological Attributes

The grafting technique significantly ($P < 0.05$) affected morphological attributes in un-grafted and grafted cucumber plants. The highest morphological attributes were observed in bottle gourd under the cleft grafting technique, followed by non-grafted grafting techniques, as compared to other grafting techniques, as mentioned in Table 1. The plants of cucumber (scion) grafted on bottle gourd using cleft grafting showed 17.5, 18, 8, 15, 12.8, 20.8, 20.1 and 15.20% increase in shoot length, root length, shoot fresh weight, root fresh weight, shoot dry weight, root dry weight, rootstock girth, and scion girth respectively, compared to un-grafted plants of cucumber. Similarly, minimum results were observed in plants of cucumber grafted onto ridge gourd, i.e., 22.6, 32.9, 21.3, 22.7, 25, 24.36, 16.22, and 24.1% reduction in shoot & root lengths, shoot & root fresh weights, shoot & root dry weights, rootstock & scion girths, respectively, relative to un-grafted cucumber plants using the single cotyledon grafting (Table. 1). Besides, the internodal distance in plants grafted on ridge gourd was 11.08% higher while 23% less in bottle gourd than that of non-grafted under single cotyledon grafting technique (Table. 1).

3.2. Gaseous Exchange Attributes

Gaseous exchange attributes were significantly ($P < 0.05$) affected by the grafting technique in grafted compared to un-grafted cucumber. The highest gaseous exchange indices were observed in the plants of cucumber that grafted onto bottle gourd in cleft grafting technique followed by non-grafted ones as compared to other grafting techniques (Fig. 1. A, B, C, D, E). The plants of cucumber which grafted on bottle gourd by using cleft grafting showed 1.27, 1.32, 1.1, 1.06, and 1.4-fold increase in photosynthetic rate *A*, transpiration rate *E*, stomatal conductance *gs*, sub-stomatal conductance *Ci* and water use efficiency WUE respectively, compared to un-grafted cucumber plants. Similarly, minimum results were observed in cucumber grafted on ridge gourd with single cotyledon grafting technique in which a reduction of 0.51, 0.67, 0.80, and 0.58-folds in *A*, *E*, gs, Ci and WUE respectively, was observed as compared to non-grafted plants (Fig. 1. A, B, C, D, E).

3.3. Biochemical Attributes

Biochemical attributes significantly ($P < 0.05$) affected by grafting technique and rootstock in grafted cucumber. The maximum biochemical indices were observed in the bottle of gourd-grafted cucumber plants using the cleft grafting technique followed by non-grafted (Fig. 2. A, B, C, D, E). Cucumber grafted on bottle gourd using cleft grafting showed 19%, 18%, 23.4%, 21.1%, and 7.5% increases in antioxidant scavenging activity ASA, superoxide dismutase SOD, catalase CAT, peroxidase POX and total phenolics contents TPC respectively, compared to un-grafted cucumber. However, minimum results were observed in cucumber grafted onto ridge gourd with a single cotyledon grafting technique in which a decrease of 38%, 31%, 43%, 29.6% and 10% in antioxidant scavenging activity ASA, superoxide dismutase SOD, catalase CAT, peroxidase POX and total phenolics contents TPC respectively, was noted as compared to non-grafted plants, by using the single cotyledon grafting (Fig. 2. A, B, C, D, E).

3.4. Yield-related Attributes

The grafting technique significantly affected yield attributes of cucumber grafted on various cucurbits ($P < 0.05$). The highest yield-oriented indices were recorded in the bottle of gourd-grafted cucumber plants using the cleft grafting technique, followed by non-grafted ones. (Fig. 3. A, B, C, D). Cucumber grafted on bottle gourd with cleft grafting showed a 10%, 16.1%, 20.3%, and 21.6% increase in average fruit weight, fruit length, fruit per plant, and yield per plant, respectively, compared to non-grafted cucumber. Minimum results were observed in the

Table 1. Shoot (S.L.) & Root Lengths (R.L.), Shoot (SFW) & Root Fresh Weights (RFW), Shoot (SDW) & Root Dry Weights (RDW), Scion (SG) & Rootstocks Girths (R.G.) and Internodal Distance (I.D.) of the cucumber plants that grafted onto indigenous cucurbits by using various grafting techniques.

Grafting Techniques		**SL (cm)**	**RL (cm)**	**SFW (g)**	**RFW (g)**	**SDW (g)**	**RDW (g)**	**SG (mm)**	**RG (mm)**	**ID (mm)**
Non-Grafted (cv Hybrid F1)		39.2±0.3c	15.2±0.09d	87.2±0.7bc	12.8±0.08b	39.2±0.38c	6.29±0.10c	2.73±0.02c	-	6.73±0.11cd
Bottle gourd +Cucumber	C. Grafting	45.0±0.6a	18.3±0.03a	94.6±0.63a	15.1±0.18a	45.0±0.66a	7.95±0.11a	3.22±0.04a	3.42±0.03a	5.18±0.04e
	S.C. Grafting	41.4±0.8bc	16.1±0.07c	89.4±0.5b	13.4±0.06b	41.4±0.83bc	6.44±0.04c	2.88±0.04c	2.99±0.06c	6.40±0.09d
	H.I. Grafting	43.6±0.7ab	17.1±0.10b	90.7±0.6b	14.8±0.08a	43.6±0.76ab	7.47±0.06b	3.03±0.02b	2.27±0.02b	5.36±0.02e
Pumpkin +Cucumber	C. Grafting	35.4±0.3d	14.6±0.04d	85.0±0.9cd	12.1±0.1c	35.4±0.30d	6.07±0.05cd	2.36±0.02d	2.58±0.02de	6.99±0.16bc
	S.C. Grafting	33.0±0.8de	12.1±0.09f	78.8±0.8ef	11.0±0.09d	33.0±0.84de	5.65±0.08d-f	2.1±0.04e	2.32±0.03fg	7.54±0.04ab
	H.I. Grafting	34.1±0.1de	13.4±0.21e	82.5±0.6de	12.2±0.2c	34.1±0.13de	5.81±0.14de	2.15±0.02de	2.4±0.02ef	7.37±0.13ab
Ridge gourd + Cucumber	C. Grafting	31.4±0.5e	12.6±0.13f	80.0±0.2f	10.6±0.07d	31.4±0.54e	5.47±0.06ef	2.21±0.04e	2.47±0.02fg	7.39±0.15ab
	SC. Grafting	29.4±0.4f	10.1±0.23h	68.59±0.5h	9.94±0.1e	29.4±0.40f	4.74±0.07g	2.07±0.02e	2.29±0.02g	7.62±0.13a
	H.I. Grafting	32.2±0.3ef	11.2±0.25g	72.88±1.3g	10.3±0.11de	32.2±0.37ef	5.22±0.04f	2.07±0.02e	2.33±0.04fg	7.76±0.18a
HSD (Tukey) value		0.77	0.19	1.05	0.17	0.77	0.12	0.045	0.047	0.159
Rootstocks Means	Non-graft Cucumber F1	39.3±0.3b	15.1±0.09b	87.2±0.7b	12.8±0.08b	39.2±0.38b	6.29±0.10b	2.73±0.02b	-	6.72±0.11c
	Bottle gourd + Cucumber	43.3±0.7a	17.2±0.06a	91.6±0.5a	14.4±0.11a	43.3±0.75a	7.29±0.07a	3.04±0.03a	3.22±0.02a	5.64±0.05d
	Pumpkin +Cucumber	34.2±0.4c	13.4±0.11c	82.1±0.7c	11.7±0.12c	34.2±0.42c	5.84±0.09c	2.20±0.03c	2.43±0.03c	7.30±0.11b
	Ridge Gourd +Cucumber	31.0±0.4d	11.3±0.20d	73.8±0.7d	10.3±0.12d	31.0±0.44d	5.15±0.06d	2.12±0.02d	2.36±0.03c	7.59±0.1a
HSD (Tukey) value		0.44	0.11	0.61	0.10	0.44	0.07	0.026	0.027	0.091
Techniques Means	C. Grafting	37.7±0.4a	15.2±0.07a	86.7±0.6a	12.6±0.11a	37.7±0.47a	6.44±0.08a	2.63±0.03a	2.80±0.03a	6.67±0.12c
	S.C. Grafting	35.5±0.6b	13.3±0.12c	81.0±0.7c	11.7±0.11b	35.7±0.61b	5.78±0.07c	2.44±0.03b	2.58±0.02c	7.07±0.09a
	H.I. Grafting	37.5±0.4a	14.2±0.16b	83.3±0.8b	12.5±0.11a	37.3±0.41a	6.20±0.08b	2.49±0.02b	2.33±0.03b	6.80±0.09b
HSD (Tukey) value		0.38	0.09	0.52	0.08	0.38	0.06	0.022	0.023	0.079

Each value of the table is the means of three replications. HSD for the rootstocks x grafting techniques was significant at $p \leq 0.05 \pm$S.E. Means with different letters are significant at $p \leq 0.05$.

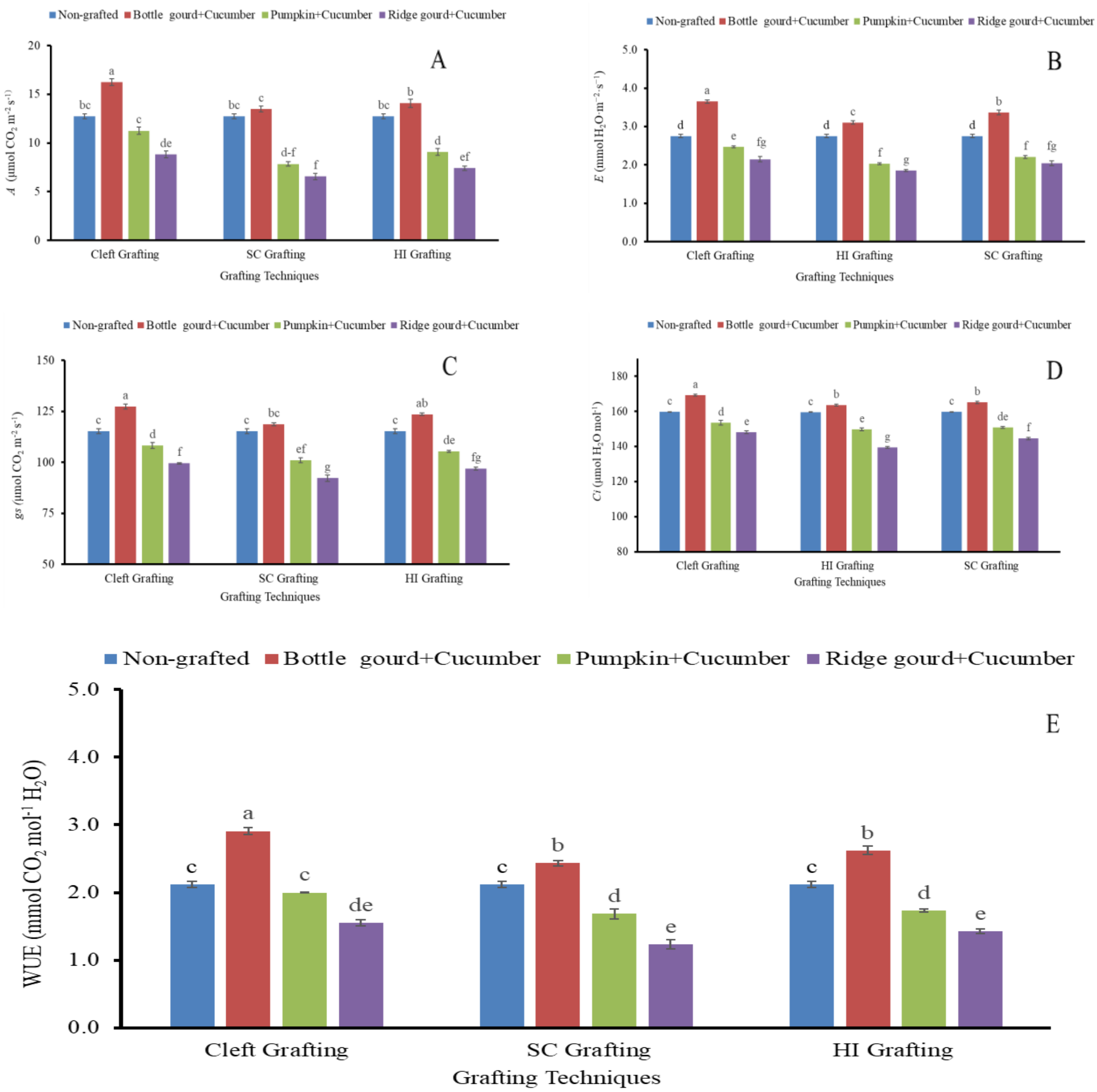

Fig. I: Photosynthetic rate (A) (A), Transpiration Rate (E) (B), Stomatal conductance (gs) (C), Sub-stomatal CO_2 (Ci) (D), and Water Use Efficiency (WUE) (E) in the plants of cucumber which grafted on various cucurbits by using various grafting techniques.

HSD for the rootstocks x grafting techniques was the significant at P≤0.05 ± S.E. Moreover, means with various letters are significant at p≤0.05.

Plants of cucumber that grafted onto ridge gourd with a single cotyledon grafting technique in which a decrease of 22.7%, 38.1%, 38.4%, and 30.4% in average fruit weight, fruit length, fruit per plant and yield per plant, respectively, was recorded as compared to non-grafted plants. (Fig. 3. A, B, C, D, E).

4. Discussion

Vegetable grafting is a horticultural surgical technique for improving plant growth and development. It improves all morphological, physiological, biochemical and yield-related attributes (Bie et al., 2017). It involves the selection of rootstocks and scions, creating a physical union, and graft union through appropriate healing, acclimatization, and transplanting (Bie et al., 2017). However, the graft union process varies due to grafting technique and environment variation. During the present

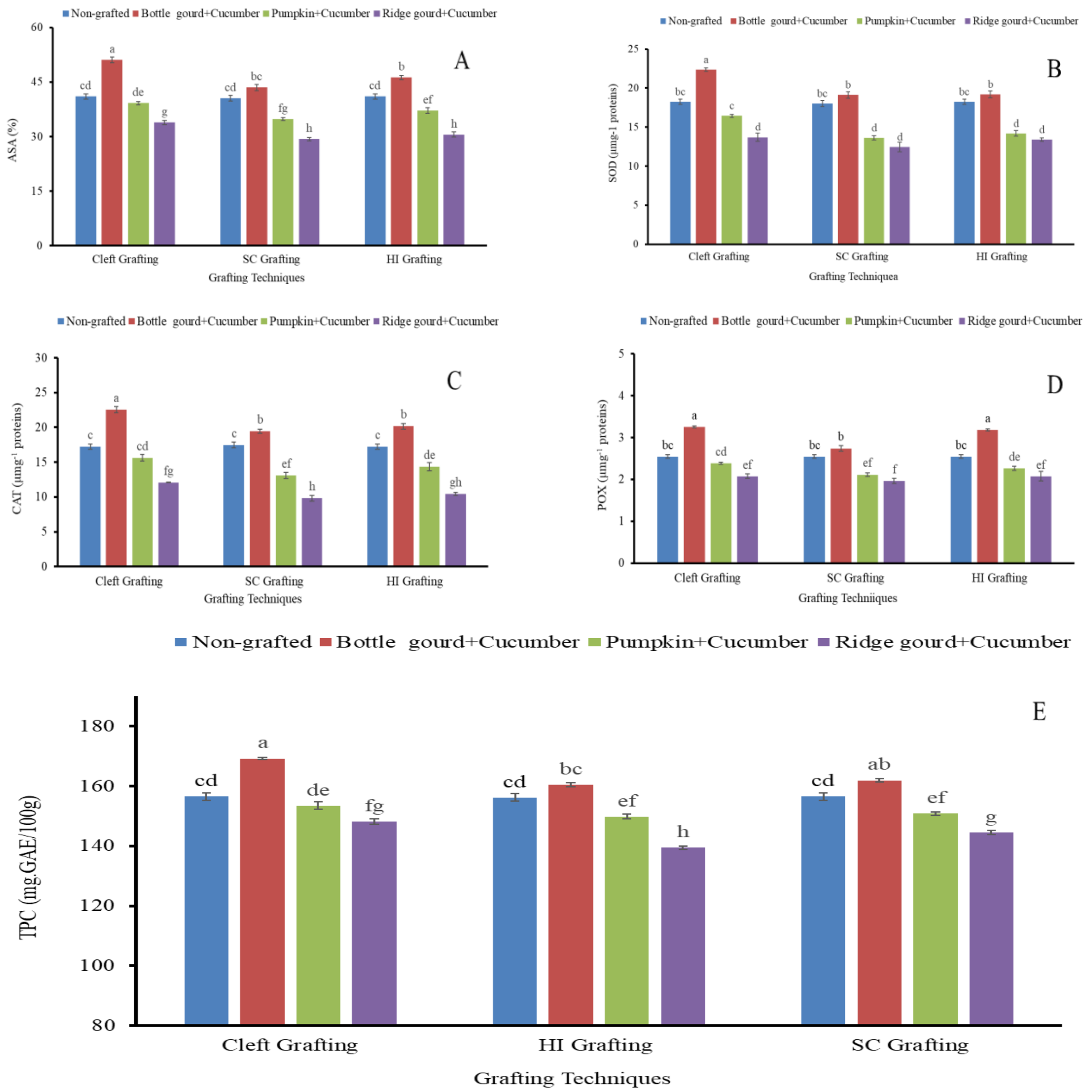

Fig. II: ASA: Antioxidant scavenging activity (A), SOD: Superoxide Dismutase (B), CAT: Catalase (C), POX: Peroxidases (D), and TPC: total phenolics contents (E) in the plants of cucumber which grafted on various cucurbits by using various grafting techniques.

HSD for the rootstocks x grafting techniques was significant at P≤0.05 ± S.E. Moreover, means with various letters are significant at p≤0.05.

study, different grafting techniques were adopted to evaluate the compatibility of different indigenous cucurbits as rootstocks for improving the cucumber growth and development confirmed through various morphological (R.L., SL, RFW, RFW, SDW, RDW, NL, rootstocks and scion girth), physiological (A, gs, Ci, WUE), biochemicals (ASA, SOD, CAT, POX and TPC) and yield (average fruit weight, fruit length, fruit diameter yield per plant). In this study, grafting cucumber onto the different indigenous rootstocks increased the biomass attributes (Table 1). However, maximum compatibility was observed when cucumber was grafted through cleft grafting technique onto bottle gourd as observed the highest morpho-physio, biochemical, and yield attributes. Our

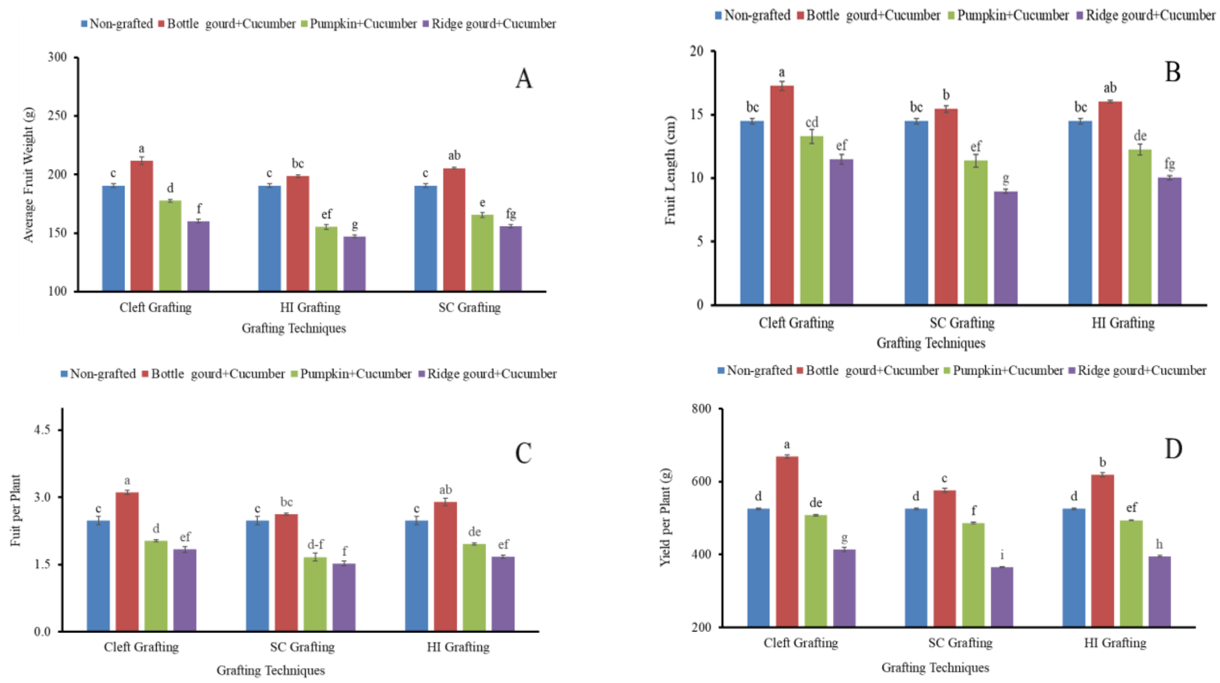

Fig. 3: Average fruit weight (A), fruit length (B), fruit per plant (C), and yield per plant (D) in the plants of cucumber which grafted on various cucurbits by using various grafting techniques.

HSD for the rootstocks x grafting techniques was significant at $P \leq 0.05 \pm$ S.E. Moreover, means with various letters are significant at $p \leq 0.05$.

results linked with Bigdelo et al., (2017); Huang et al., (2016a), who reported that the root system (number of roots, root volume, and root forks) of the grafted plant was more developed as compared to the un-grafted plants which helped up taking higher water and nutrients to the leaves, thereby higher photosynthates production. Similarly, grafting improved the all-physiological attributes such as A, E, Ci, gs, and WUE in the plants of cucumber that grafted on the bottle gourd by using the cleft graft technique (Fig. 1. A, B, C, D, E). This improvement might be due to its protective role of grafting as it up-regulates the intake of CO2 and higher Rubisco activity(Giné et al., 2017; Li et al., 2016). In this study, grafting cucumber onto bottle gourd by using the cleft grafting technique increased the biochemical attributes (ASA, SOD, CAT, POX and TPC) relative to the non-grafted cucumber plants (Fig. 2. A, B, C, D, E). The rootstocks increased the stress tolerance of scion, possibly by the activation of antioxidants, SOD and CAT. The increase of the CAT and SOD decreases the H2O2 and lipid peroxidation in the tissues of plants (Nawaz et al., 2018). ROS produce in the cell, which are removed by the ASA, SOD and CAT (Rahman and Singh, 2019). Catalase (CAT) is a major scavenging enzyme, and SOD has an early defence system against ROS (Wang et al., 2013). The successful graft union of the rootstocks with the compatible scion helps improve the all-biochemical attributes such as ASA, SOD, CAT, POX and TPC. The yield-related attributes, such as average fruit weight, fruit length, and fruit diameter yield per plant, were increased in the bottle gourd grafted cucumber plants under the cleft grafting technique (Fig. 3. A, B, C, D, E). Our results correlate with the previous study of Xing et al., (2015), who reported improved watermelon yield and fruit quality probably by enhancing the abiotic and biotic stress tolerance. The crop yield and quality of the fruits are enhanced due to graft compatibility between rootstocks and scion, which causes early flowering healthy growth and increases the crop duration (Goldschmidt, 2014).

5. Conclusion

Grafting is vital to improving the productivity and quality of cucumber by utilizing an appropriate scion rootstock combination and grafting technique. The current study confirmed using the cleft grafting technique on bottle gourd for improving cucumber growth and productivity.

6. REFERENCES

AARI, 2017. Ayyub Agricultural Research Institute, Government of Punjab, Pakistan. http://www.aari.punjab.gov.pk/far mer services/forfarmers/tunnel-gardening (Accessed on January 24, 2017)

Abdelaal, K.A., Y.S. Mazrou and Y.M. Hafez. 2020. Silicon foliar application mitigates salt stress in sweet pepper plants by enhancing water status, photosynthesis, antioxidant enzyme activity and fruit yield. Plants. 9:733.

Amaro, A.C.E., A.C. Macedo, A.R.P. Ramos, R. Goto, E.O. Ono and J.D. Rodrigues. 2014. The use of grafting to improve the net photosynthesis of cucumber. Theoretical and Experimental Plant Physiology. 26:241-249.

Bantis F., G. Tsiolas, E. Mouchtaropoulou , I. Tsompanoglou, A.N. Polidoros, A. Argiriou and A. Koukounaras. 2021. Comparative Transcriptome Analysis in Homoand Hetero-Grafted Cucurbit Seedlings. Front. Plant Sci. 12:691069. doi: 10.3389/fpls.2021.691069

Bie, Z., M. Azher Nawa, Y. Huang, J. Lee and G. Colla. 2017. Introduction to vegetable grafting in vegetable grafting: principles and practices. U.K.: CAB International Oxfordshire.216-244.

Bigdelo, M., M.R. Hassandokht, Y. Rouphael, G. Colla, F. Soltani and R. Salehi. 2017. Evaluation of bitter apple ('Citrullus colocynthis'(L.) Schrad) as potential rootstock for watermelon. Australian Journal of Crop Science. 11:727-732.

Bletsos, F.A. and C.M. Olympios. 2008. Rootstocks and grafting of tomatoes, peppers and eggplants for soilborne disease resistance, improved yield and quality. The European Journal of Plant Science and Biotechnology. 2:62-73.

Camalle, M.D., N. Sikron, U. Zurgil, J. Khadka, S. Pivonia, A. Pěnčík, O. Novák, A. Fait and N. Tel-Zur. 2021. Does scion–rootstock compatibility modulate photoassimilate and hormone trafficking through the graft junction in melon–pumpkin graft combinations? Plant Science. 306:110852.

Cuevas, J., I.N. Daliakopoulos, F. Del Moral, J.J. Hueso and I.K. Tsanis. 2019. A review of soil-improving cropping systems for soil salinization. Agronomy. 9:295.

Gilardi, G., P. Colla, M. Pugliese, M. Baudino, M.L. Gullino and A. Garibaldi. 2014. Control of Colletotrichum coccodes on tomato by grafting and soil amendments. Journal of Phytopathology. 162:116-123.

FAO. 2023. Agricultural production statistics 2000–2022. FAOSTAT Analytical Briefs, No. 79. Rome.
https://doi.org/10.4060/cc9205en.

Giné, A., C. González, L. Serrano and F.J. Sorribas. 2017. Population dynamics of Meloidogyne incognita on cucumber grafted onto the Cucurbita hybrid RS841 or ungrafted and yield losses under protected cultivation. European journal of plant pathology. 148:795-805.

Gish, R. and G. Gikalo. 2012. Vegetable growing in the South of Russia. Krasnodar: EDVI.

Goldschmidt, E.E. 2014. Plant grafting: new mechanisms, evolutionary implications. Frontiers in plant Science. 5:727.

Guo, J., W. Xu, Y. Hu, J. Huang, Y. Zhao, L. Zhang, C.-H. Huang and H. Ma. 2020. Phylotranscriptomics in Cucurbitaceae reveal multiple whole-genome duplications and key morphological and molecular innovations. Molecular plant. 13:1117-1133.

Huang, Y., Y. Jiao, M.A. Nawaz, C. Chen, L. Liu, Z. Lu, Q. Kong, F. Cheng and Z. Bie. 2016a. Improving magnesium uptake, photosynthesis and antioxidant enzyme activities of watermelon by grafting onto pumpkin rootstock under low magnesium. Plant and Soil. 409:229-246.

Huang, Y., L. Zhao, Q. Kong, F. Cheng, M. Niu, J. Xie, M.A. Nawaz and Z. Bie. 2016b. Comprehensive mineral nutrition analysis of watermelon grafted onto two different rootstocks. Horticultural Plant Journal. 2:105-113.

Johnson, S.J., P. Kreider and C.A. Miles. 2011. Vegetable grafting: eggplants and tomatoes.

Kumar, P., Y. Rouphael, M. Cardarelli and G. Colla. 2017. Vegetable grafting as a tool to improve drought resistance and water use efficiency. Frontiers in plant science. 8:1130.

Kuşvuran, Ş., K. Elif and Ş.Ş. Ellialtioğlu. 2021. Role of grafting in tolerance to salt stress in melon (Cucumis melo L.) plants: ion regulation and antioxidant defense systems. Biotech Studies 30, 22-35.Lee, J.-M., C. Kubota, S. Tsao, Z. Bie, P.H. Echevarria, L. Morra and M. Oda. 2010. Current status of vegetable grafting: Diffusion, grafting techniques, automation. Scientia Horticulturae. 127:93-105.

Lee, J.-M. and M. Oda. 2002. Grafting of herbaceous vegetable and ornamental crops. HORTICULTURAL REVIEWS-WESTPORT THEN NEW YORK-. 28:61-124.

Lee, J.M., H.J. Bang and H.S. Ham. 1998. Grafting of vegetables (grafting and raising of seedlings, for further development of horticulture in East Asia). Journal of the Japanese Society for Horticultural Science. 67:1098-1104.

Li, H., G.J. Ahammed, G. Zhou, X. Xia, J. Zhou, K. Shi, J. Yu and Y. Zhou. 2016. Unraveling main limiting sites of photosynthesis under below-and above-ground heat stress in cucumber and the alleviatory role of luffa rootstock. Frontiers in Plant Science. 7:746.

Liang, J. et al. Grafting improves nitrogen-use efficiency by regulating the nitrogen uptake and metabolism under low-nitrate conditions in cucumber. 2021. Scientia Horticulturae 289, 110454.

Lichtenthaler, H.K. and C. Buschmann. 2001. Extraction of phtosynthetic tissues: chlorophylls and carotenoids. Current protocols in food analytical chemistry. 1:F4. 2.1-F4. 2.6.

Liu, D., J. Zou, Q. Meng, J. Zou and W. Jiang. 2009. Uptake and accumulation and oxidative stress in garlic (Allium sativum L.) under lead phytotoxicity. Ecotoxicology. 18:134-143.

Martínez-Ballesta, M.C., C. Alcaraz-López, B. Muries, C. Mota-Cadenas and M. Carvajal. 2010. Physiological aspects of rootstock–scion interactions. Scientia Horticulturae. 127:112-118.

Mauro, R.P., M. Agnello, M. Distefano, L. Sabatino, A. San Bautista Primo, C. Leonardi and F. Giuffrida. 2020. Chlorophyll fluorescence, photosynthesis and growth of tomato plants as affected by long-

term oxygen root zone deprivation and grafting. Agronomy. 10:137.
Melnyk, C.W. 2017. Plant grafting: insights into tissue regeneration. Regeneration. 4:3-14.
Melnyk, C.W., A. Gabel, T.J. Hardcastle, S. Robinson, S. Miyashima, I. Grosse and E.M. Meyerowitz. 2018. Transcriptome dynamics at Arabidopsis graft junctions reveal an intertissue recognition mechanism that activates vascular regeneration. Proceedings of the National Academy of Sciences. 115:E2447-E2456.
Miao, L., Q. Li, T.-S. Sun, S. Chai, C. Wang, L. Bai, M. Sun, Y. Li, X. Qin and Z. Zhang. 2021. Sugars promote graft union development in the heterograft of cucumber onto pumpkin. Horticulture Research. 8.
Mimica-Dukić, N., B. Božin, M. Soković, B. Mihajlović and M. Matavulj. 2003. Antimicrobial and antioxidant activities of three Mentha species essential oils. Planta medica. 69:413-419.
Moore, R. 1984. A model for graft compatibility-incompatibility in higher plants. American Journal of Botany. 71:752-758.
Nawaz, M.A., M. Imtiaz, Q. Kong, F. Cheng, W. Ahmed, Y. Huang and Z. Bie. 2016. Grafting: a technique to modify ion accumulation in horticultural crops. Frontiers in plant science. 7:1457.
Nawaz, M.A., Y. Jiao, C. Chen, F. Shireen, Z. Zheng, M. Imtiaz, Z. Bie and Y. Huang. 2018. Melatonin pretreatment improves vanadium stress tolerance of watermelon seedlings by reducing vanadium concentration in the leaves and regulating melatonin biosynthesis and antioxidant-related gene expression. Journal of Plant Physiology. 220:115-127.
Nawaz, M.A., F. Shireen, Y. Huang, B. Zhilong, W. Ahmed and B.A. Saleem. 2017. Perspectives of vegetable grafting in Pakistan, current status, challenges and opportunities. Int J Agric Biol. 19:1165-74.
Noor, R.S., Z. Wang, M. Umair, M. Yaseen, M. Ameen, S.-U. Rehman, M.U. Khan, M. Imran, W. Ahmed and Y. Sun. 2019. Interactive effects of grafting techniques and scion-rootstocks combinations on vegetative growth, yield and quality of cucumber (Cucumis sativus L.). Agronomy. 9:288.
Oda, M. 2002. Grafting of vegetable crops. Scientific report of the graduate school of agriculture and biological sciences, Osaka Prefecture University. 54:49-72.
Padilla, Y.G., R. Gisbert-Mullor, L. López-Serrano, S. López-Galarza and Á. Calatayud. 2021. Grafting enhances pepper water stress tolerance by improving photosynthesis and antioxidant defense systems. Antioxidants. 10:576.
Parthasarathi, T., J.E. Ephrath and N. Lazarovitch. 2021. Grafting of tomato (Solanum lycopersicum L.) onto potato (Solanum tuberosum L.) to improve salinity tolerance. Scientia Horticulturae. 282:110050.
Rahman, Z. and V.P. Singh. 2019. The relative impact of toxic heavy metals (THMs)(arsenic (As), cadmium (Cd), chromium (Cr)(VI), mercury (Hg), and lead (Pb)) on the total environment: an overview. Environmental monitoring and assessment. 191:1-21.
Razzaq, K., A.S. Khan, A.U. Malik and M. Shahid. 2013. Ripening period influences fruit softening and antioxidative system of 'Samar Bahisht Chaunsa'mango. Scientia Horticulturae. 160:108-114.
Sandoval, M., P. Sánchez and G. Alcántar. 2007. Principios de la hidroponía y del fertirriego. Nutrición de cultivos. Mundi Prensay Colegio de

Postgraduados. México, DF, 373-438.
Soltan, M., F. Elaidy, J. Scheerens and M. Kleinhenz. 2017. Grafting, scion and rootstock effects on survival rate, vegetative growth and fruit yield of high tunnel-grown grafted pepper (Capsicum annuum L.) plants. Adv. Crop. Sci. Tech. 5:2.
Štajner, D. and B. Popović. 2009. Comparative study of antioxidant capacity in organs of different Allium species. Open Life Sciences. 4:224-228.
Talpur, M.A., Hafeezullah, S. Amin. 2022. Fruit, vegetables, and condiments statistics of Pakistan 2020-21. Economic wing, Ministry of National Food Security and Research Islamabad, Government of Pakistan.
Traka-Mavrona, E., M. Koutsika-Sotiriou and T. Pritsa. 2000. Response of squash (Cucurbita spp.) as rootstock for melon (Cucumis melo L.). Scientia Horticulturae. 83:353-362.
Ulas, F. 2021. Response of different rootstocks on vegetative growth, fruit and seed yield of eggplant (Solanum melongena L.). Genetika. 53:593-608.
Ulas, F., A. Aydın, A. Ulas and H. Yetisir. 2019. Grafting for sustainable growth performance of melon (Cucumis melo) under salt stressed hydroponic condition. European Journal of Sustainable Development. 8:201-201.
Usanmaz, S. and K. Abak. 2019. Plant growth and yield of cucumber plants grafted on different commercial and local rootstocks grown under salinity stress. Saudi Journal of Biological Sciences. 26:1134-1139.
Uttekar, V., L. Gabhale, Y. Parulekar, J. Kadam and P. Sanap. 2021. Effect of various potting media on growth and development of Chilli (Capsicum annuum L.) seedlings for grafting.
Velasco Alvarado, M.D.J. 2013. Anatomía y manejo agronómico de plantas injertadas en jitomate (Solanum lycopericum). Universidad Autónoma Chapingo.
Wang, P., X. Sun, C. Li, Z. Wei, D. Liang and F. Ma. 2013. Long-term exogenous application of melatonin delays drought-induced leaf senescence in apple. Journal of pineal research. 54:292-302.
Xing, W.-W., L. Li, P. Gao, H. Li, Q.-S. Shao, S. Shu, J. Sun and S.-R. Guo. 2015. Effects of grafting with pumpkin rootstock on carbohydrate metabolism in cucumber seedlings under Ca (NO3) 2 stress. Plant Physiology and Biochemistry. 87:124-132.
Xu, Y., D. An, D. Liu, A. Zhang, H. Xu and B. Li. 2012. Molecular mapping of QTLs for grain zinc, iron and protein concentration of wheat across two environments. Field Crops Research. 138:57-62.
Yanyan, Y., W. Shuoshuo, W. Min, G. Biao and S. Qinghua. 2018. Effect of different rootstocks on the salt stress tolerance in watermelon seedlings. Horticultural plant journal. 4:239-249.
Yang et al. Bottle gourd rootstock-grafting promotes photosynthesis by regulating the stomata and non-stomata performances in leaves of watermelon seedlings under NaCl stress. J. Plant Physiology. 186;50-58
Ziaf, K., I. Ahmad, H. Hamid, M.A. Ghani, M.W. Haider and A. Noor. 2021. Nutrient uptake, growth, yield and quality of cucumber grown in various growing media. Agrobiological Records. 6:18-26. https://doi.org/10.47278/journal.abr/2021.007.