Journal of Applied Horticulture, 25(2): 150-154, 2023

DOI: https://doi.org/10.37855/jah.2023.v25i02.26

Journal of Applied Horticulture
ISSN: 0972-1045

Effects of discarded cheese-whey amended substrate on growth and flowering of different snapdragon cultivars (*Antirrhinum majus* L.)

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Abstract

The recycling of organic waste as a feedstock for the plant use emerges to be an eco-friendly process for the production of various fruit, vegetable, and ornamental crops. Cheese-whey has very short shelf life, therefore, in the present study the wasted cheese-whey is used as organic material to observe its effect on ornamental plant. In this study, seven commercial cultivars of snapdragon (Magic Carpet, Antiquity Sunset, Day and Night, Chuckles, Illumination, Madame Butterfly, and Twilight) were planted in pots containing either (1) 1:3:1 ratio of sand, peat-based compost, and perlite substrate (control), or (2) 1:3:1 ratio of sand, peat-based compost, and perlite substrate, which was amended by adding 200 mL per pot cheese-whey. These pots were placed in a glasshouse, under ambient environment. The layout of the experiment was two-factorial completely randomized design with six replicates. All plant growth and flowering parameters were significantly ($P \leq 0.05$) affected by substrates. Snapdragon cultivars grown in cheese-whey amended substrate displayed maximum plant height, number of leaf per plant, leaf area, leaf fresh weight, leaf dry weight, plant fresh weight, plant dry weight, specific leaf weight, and leaf area ratio. Comparing the cultivars, it was observed that the cultivar Day and Night had maximum days to flowering, plant height, number of leaf per plant, leaf area, leaf fresh weight, leaf dry weight, plant fresh weight, plant dry weight, specific leaf weight, and leaf area ratio. The interaction of the both factors indicated that all snapdragon cultivars had significantly promising results when grown in cheese-whey amended substrate compared to control plants.

Key words: Snapdragon, *Antirrhinum majus* L., cheese-whey, substrate, growth, flowering

Introduction

In the process of global economic growth and development, agriculture has played a strategic part (Weatherspoon *et al.,* 2001). However, the rapid increase in agricultural productivity has put more pressure on the environment's natural resources (Pawlak and Kołodziejczak, 2020). The massive amount of waste material produced by the intensive crop cultivation is one of its major issues. The majority of this material is biomass waste. This kind of residue emerges into a resource with significant potential for the extraction of high-value by-products (Duque-Acevedo *et al.,* 2020). Waste biomass has great recycling potential due to abundancy and having no harmful effects on environment. Recycling of organic waste as a feedstock for plants is an eco-friendly method of cultivating various fruit, vegetable, and ornamental crops. The re-use of such waste material also supports the economic development in sustainable way (Munir *et al.,* 2020; Thomson *et al.,* 2022). The value of organic waste and other residual materials from bio-based enterprises and private residences is increasing. The wasted materials that were once a strain on the economy have become valuable resources (Klitkou *et al.,* 2019).

The significance of dairy industry to the rural agricultural economy cannot be overstated. The dairy products such as milk, milk powder, butter, and cheese are widely consumed and enjoyed all over the world. When it comes to processing, fermenting, and consuming dairy products, there has been a staggering amount of ingenuity and innovation over the last couple of millennia. The global dairy industry was valued at ca. 871 billion US dollars in 2021, and by 2026, it is expected to have increased to ca. 1,128 billion (Jaganmai and Jinka, 2017, Shahbandeh, 2022). The growing demand for dairy products across the globe leads to the expansion of the dairy sector and an increase in waste production. It is estimated that ca. 20% of dairy products are wasted (Askew, 2022). Cheese-whey, dairy sludges, milk and milk products residue, and wastewater are the main wastes generated by dairy industries. This waste contain both organic and inorganic contents and have significant nutrient concentrations, as well as biological and chemical oxygen demands. They can also contain a variety of chemicals, both acid and alkaline, and sterilizing agents. Pollution due to the waste of dairy industry affects the air, soil and water quality (De Jesus *et al.,* 2015; Raghunath *et al.,* 2016; Ahmad *et al.,* 2019; Sar *et al.,* 2022. It is therefore needed to take initiatives not only to reduce dairy waste but to recycle and utilize the wasted material, which can lead to enhanced sustainability, including reduced environmental impacts and cost savings (Eriksson *et al.,* 2014).

One of the largest reserves of food protein is found in whey, the liquid byproduct of the production of cheese, casein, and yoghurt. It includes 80–90% of the total volume of milk and about 50% of the nutrients found in the original milk (soluble protein, lactose, vitamins, and minerals). Sweet whey is a by-product of making hard, semi-hard, or soft cheese with rennet casein, whereas acid whey is produced by using mineral-acid precipitated casein (Smithers, 2008; Yadav *et al.,* 2015). The application of whey at different concentrations (25-100%) on tomato, okra, corn, and potatoes significantly increased the vegetative growth, yield and fruit quality (Sharratt *et al.,* 1962; Al-Mughrabi, 2007; Pane *et al.,* 2012; Abed *et al.,* 2016; Mahmood *et al.,* 2020). Application of whey improved the soil structure and trace elements (Al, Fe, B, Cu, Zn, Mn, and Cr) concentration (Robbins and Lehrsch, 2020). Cheese-whey can improve the physical condition of sodic soils or those susceptible to erosion by increasing their aggregate stability (Lehrsch and Robbins, 1996). This study sought to investigate the impact of wasted cheese-whey amended substrate on the growth and flowering of ornamental snapdragon cultivars and to compare it with the traditional substrate. The outcome of the study identified the recycling of one of the dairy wasted materials in order to reduce its negative pollutant effects.

Materials and methods

The glasshouse experiment was conducted at the Date Palm Research Center of Excellence, Training and Research Station, King Faisal University, Al-Ahsa, Saudi Arabia during 2020 and 2021 (Latitude 25° 16' 7.068'' N and Longitude 49° 42' 27.522'' E). Seeds of seven snapdragon cultivars Magic Carpet, Antiquity Sunset, Day and Night, Chuckles, Illumination, Madame Butterfly, and Twilight were obtained from Sutton Seeds, Devon, England. Seeds were sown into 84 cells seed plug trays containing peat-based compost. Seed trays were placed in an environment-controlled growth chamber (Microclima 1000, Snijders Scientific B.V. Tilburg, Holland) at 23 ± 2°C temperature providing 70 μmol m^{-2} s^{-1} photosynthetic photon flux density (PPFD) using white LED lights installed at one meter tray height with a 16 h d^{-1} photoperiod.

After 75% seed germination, plants were transplanted into 10 cm plastic pots. These pots were divided into two groups based on different substrates: (1) Pots were filled in with 1:3:1 ratio of sand, peat-based compost, and perlite (control), and (2) Pots were filled in with 1:3:1 ratio of sand, peat-based compost, and perlite, however, this substrate was amended by adding 200 mL per pot cheese-whey. These pots were then transferred in a glasshouse, under ambient environment. The temperature, relative humidity, and light intensity within the glasshouse was recorded every 5 seconds using a HOBO Analog/Temp/RH/Light data logger (MX1104, Onset Computer Corporation, MA, USA).

The experiment was laid out on two-factorial completely randomized design (CRD) having six replications for each treatment. The first factor was seven commercial cultivars of snapdragon (Magic Carpet, Antiquity Sunset, Day and Night, Chuckles, Illumination, Madame Butterfly, and Twilight) and the second factor was two types of substrates (control and cheese-whey). The wasted cheese-whey was obtained from the local superstore and was analyzed in the Biochemistry laboratory, King Faisal University, Saudi Arabia. The cheese-whey analysis result indicated that it had 9% protein, 65% lactose, 0.4% fats, 333 mg L^{-1} total nitrogen, 57 mg L^{-1} available nitrogen, 98 mg L^{-1} total phosphorus, 341 mg L^{-1} total potassium, 54 mg L^{-1} total magnesium, 251 mg L^{-1} calcium, 483 mg L^{-1} sodium, 45 mg L^{-1} sulphur, 0.15 mg L^{-1} lead, 0.01 mg L^{-1} nickel, < 0.01 mg L^{-1} cadmium, 0.05 mg L^{-1} chromium, < 0.01 mg L^{-1} arsenic, < 0.01 mg L^{-1} mercury, 3.32 mg L^{-1} zinc, 0.91 mg L^{-1} copper, 0.02 mg L^{-1} molybdenum, 0.02 mg L^{-1} selenium, 4.8 pH, 4.14 mmhos electrical conductivity, 1.24% dry matter (AOAC, 2016).

Plant nutrients were given in the form of a water soluble fertilizer 15:15:15. To avoid *Pythium*, water was applied manually every two or three days as required. Plants in each treatment were observed daily until flower opening (corolla fully opened). The following parameters were recorded during the study according to AOAC standard methods (AOAC, 2016): days to flowering, plant height, number of leaf per plant, leaf area, leaf fresh weight, leaf dry weight, plant fresh weight, plant dry weight, specific leaf area, specific leaf weight, leaf weight ratio, leaf area ratio, net assimilation rate, and relative growth rate. The collected data were statistically analyzed according to Gomez and Gomez (1984), using Statistical Analysis Software, Release 9.4 (SAS Institute, North Carolina, USA), and the Duncan Multiple Range Test (DMRT) was applied to determine the least significance difference between the treatment means (Waller and Duncan, 1969). The two-way factorial completely randomized design layout is as below:

	Factor-A (Cultivars)	Factor-B (Substrates)
1	Magic Carpet	(1) Control (2) Cheese-whey
2	Antiquity Sunset	(1) Control (2) Cheese-whey
3	Day and Night	(1) Control (2) Cheese-whey
4	Chuckles	(1) Control (2) Cheese-whey
5	Illumination	(1) Control (2) Cheese-whey
6	Madame Butterfly	(1) Control (2) Cheese-whey
7	Twilight	(1) Control (2) Cheese-whey

Results and discussion

Data presented in Table 1 revealed that there was a significant ($P \leq 0.05$) difference among means of different snapdragon cultivars regarding days to flowering, plant height, number of leaf per plant, leaf area, leaf fresh weight, leaf dry weight, plant fresh weight, plant dry weight, specific leaf area, specific leaf weight, leaf weight ratio, leaf area ratio, net assimilation rate, and relative growth rate. Maximum days to flowering (104.50 days), plant height (55.95 cm), number of leaf per plant (30.25), leaf area (203.22 cm^2), leaf fresh weight (9.11 g), leaf dry weight (1.16 g), plant fresh weight (51.97 g), and plant dry weight (5.20 g) were recorded in cultivar Day and Night. Cultivar Illumination (103.58 days) was statistically at par with cultivar Day and Night regarding days to flowering parameter, however, it had highest specific leaf area (289.43 cm^2 g^{-1}) followed by cultivar Magic Carpet (282.07 cm^2 g^{-1}). Similarly, cultivar Madame Butterfly (54.08 cm) was statistically alike with cultivar Day and Night regarding plant height parameter. The specific leaf weight was highest in cultivars Antiquity Sunset and Day and Night (0.0058 g cm^{-2}). The leaf weight ratio was statistically similar but maximum in cultivars Day and Night (0.130), Antiquity Sunset (0.126), Twilight (0.124), and Madame Butterfly (0.121). Similarly, leaf area ratio (45.08) was highest in cultivar Twilight, whereas cultivar Magic Carpet had maximum net assimilation rate (0.0163 g g^{-1} d^{-1}) and relative growth rate (0.326 g cm^{-2} d^{-1}).

The comparative analysis between the control and cheese-whey amended substrate indicated that apart from days to flowering there was a significant ($P \leq 0.05$) difference regarding plant height, number of leaf per plant, leaf area, leaf fresh weight, leaf dry weight, plant fresh weight, plant dry weight, specific leaf area, specific leaf weight, leaf weight ratio, leaf area ratio, net assimilation rate, and relative growth rate attributes (Table 1). Snapdragon plants growing in cheese-whey amended substrates had higher plant height (43.87 cm), number of leaf per plant (25.40), leaf area (151.53 cm^2), leaf fresh weight (5.82 g),

Table 1. Effect of cheese-whey amended substrate on the days to flowering (DF), plant height (PH), number of leaf per plant (L/P), leaf area (LA), leaf fresh weight (LFW), leaf dry weight (LDW), plant fresh weight (PFW), plant dry weight (PDW), specific leaf area (SLA), specific leaf weight (SLW), leaf weight ratio (LWR), leaf area ratio (LAR), net assimilation rate (NAR), and relative growth rate (RGR) of seven commercial cultivars of snapdragon

Treatments	DF (days)	pH (cm)	L/P	LA (cm^2)	LFW (g)	LDW (g)	PFW (g)	PDW (g)	SLA ($cm^2 g^{-1}$)	SLW ($g cm^{-2}$)	LWR	LAR	NAR ($g g^{-1} d^{-1}$)	RGR ($g cm^{-2} d^{-1}$)
A. Cultivars														
MAG	84.25^{D}	17.52^{E}	16.08^{F}	64.78^{D}	1.89^{E}	0.24^{E}	18.52^{E}	2.32^{E}	282.07^{AB}	0.0036^{B}	0.063^{B}	28.60^{C}	0.0163^{A}	0.326^{A}
ANT	99.75^{B}	34.66^{D}	19.08^{E}	102.26^{C}	3.36^{D}	0.59^{C}	26.71^{D}	2.67^{D}	180.56^{D}	0.0058^{A}	0.126^{A}	38.36^{B}	0.0099^{B}	0.249^{B}
DN	104.50^{A}	55.95^{A}	30.25^{A}	203.22^{A}	9.11^{A}	1.16^{A}	51.97^{A}	5.20^{A}	176.49^{D}	0.0058^{A}	0.130^{A}	39.68^{AB}	0.0051^{D}	0.124^{C}
CHK	93.00^{C}	47.75^{B}	24.08^{C}	137.87^{B}	4.42^{C}	0.54^{CD}	40.24^{C}	4.02^{C}	262.34^{B}	0.0039^{C}	0.076^{B}	34.33^{BC}	0.0076^{C}	0.163^{C}
ILL	103.58^{A}	45.33^{C}	22.08^{D}	139.31^{B}	4.45^{C}	0.48^{D}	38.19^{C}	3.82^{C}	289.43^{A}	0.0034^{C}	0.073^{B}	36.49^{B}	0.0074^{C}	0.171^{C}
MAD	100.67^{B}	54.08^{A}	28.25^{B}	196.40^{A}	8.01^{B}	0.95^{B}	49.41^{B}	4.94^{B}	212.73^{C}	0.0048^{B}	0.121^{A}	39.91^{AB}	0.0052^{D}	0.132^{C}
TWL	100.75^{B}	35.00^{D}	19.91^{E}	110.45^{C}	3.44^{D}	0.57^{CD}	24.73^{D}	2.47^{DE}	198.85^{CD}	0.0051^{B}	0.124^{A}	45.08^{A}	0.0093^{B}	0.270^{AB}
LSD	2.30*	2.09*	1.55	16.84*	0.76*	0.09*	2.34*	0.25*	26.91*	0.0006*	0.035*	5.82*	0.0008*	0.056*
B. Substrates														
Control	98.38^{A}	39.07^{B}	20.23^{B}	121.12^{B}	4.08^{B}	0.53^{B}	33.54^{B}	3.41^{B}	248.14^{A}	0.0042^{B}	0.153^{A}	35.19^{B}	0.0098^{A}	0.329^{A}
Cheese-whey	97.76^{A}	43.87^{A}	25.40^{A}	151.53^{A}	5.82^{A}	0.76^{A}	37.82^{A}	3.85^{A}	209.71^{B}	0.0051^{A}	0.051^{B}	39.81^{A}	0.0075^{B}	0.081^{B}
LSD	1.23^{NS}	1.11*	0.83*	9.00*	0.41*	0.04*	1.25*	0.13*	14.38*	0.0003*	0.018*	3.11*	0.0004*	0.030*
C. Cultivar x Substrate Interaction														
MAG × Control	83.67^{H}	15.46^{I}	12.50^{J}	50.33^{H}	1.24^{G}	0.15^{I}	16.20^{J}	2.04^{I}	319.09^{A}	0.0031^{K}	0.081^{BD}	25.52^{E}	0.0199^{A}	0.506^{A}
MAG × Cheese-whey	84.83^{H}	19.58^{H}	19.66^{G}	79.22^{G}	2.54^{F}	0.32^{H}	20.85^{I}	2.61^{GH}	245.05^{CD}	0.0041^{GJ}	0.046^{D}	31.68^{DE}	0.0127^{B}	0.146^{DE}
ANT × Control	100.83^{CE}	32.15^{G}	17.16^{H}	92.06^{FG}	2.73^{F}	0.48^{FG}	24.76^{H}	2.47^{H}	196.14^{EG}	0.0053^{BE}	0.197^{A}	37.31^{BD}	0.0109^{C}	0.406^{B}
ANT × Cheese-whey	98.67^{E}	37.18^{F}	21.00^{FG}	112.47^{EF}	3.98^{E}	0.70^{CE}	28.67^{G}	2.86^{G}	164.98^{G}	0.0063^{A}	0.055^{D}	39.41^{BD}	0.0089^{D}	0.093^{EF}
DN × Control	105.67^{A}	52.89^{B}	27.83^{C}	185.50^{B}	7.89^{C}	1.01^{B}	48.86^{BC}	4.89^{BC}	185.63^{FG}	0.0055^{AD}	0.207^{A}	38.09^{BD}	0.0054^{FG}	0.205^{CD}
DN × Cheese-whey	103.33^{AC}	59.01^{A}	32.66^{A}	220.94^{A}	10.33^{A}	1.32^{A}	55.09^{A}	5.51^{A}	167.36^{G}	0.0061^{AB}	0.053^{D}	41.27^{B}	0.0047^{G}	0.044^{F}
CHK × Control	94.67^{F}	45.33^{DE}	21.66^{FG}	124.15^{E}	3.62^{EF}	0.44^{GH}	38.19^{EF}	3.82^{EF}	283.87^{AB}	0.0036^{IK}	0.116^{B}	32.74^{CE}	0.0083^{D}	0.262^{C}
CHK × Cheese-whey	91.33^{G}	50.16^{BC}	26.50^{CD}	151.59^{CD}	5.22^{D}	0.63^{DE}	42.30^{D}	4.23^{D}	240.82^{CD}	0.0043^{FI}	0.036^{D}	35.92^{BD}	0.0068^{E}	0.064^{F}
ILL × Control	104.83^{AB}	43.16^{E}	19.66^{G}	123.17^{E}	3.59^{EF}	0.39^{GH}	36.36^{F}	3.64^{F}	311.42^{A}	0.0032^{JK}	0.109^{BC}	33.94^{BD}	0.0081^{D}	0.275^{C}
ILL × Cheese-whey	102.33^{BD}	47.50^{CD}	24.50^{DE}	155.45^{C}	5.31^{D}	0.58^{EF}	40.02^{DE}	4.00^{DE}	267.43^{BC}	0.0037^{HK}	0.037^{D}	39.03^{BD}	0.0066^{EF}	0.068^{EF}
MAD × Control	99.67^{DE}	51.83^{B}	26.16^{CD}	181.01^{B}	6.96^{C}	0.82^{C}	47.36^{C}	4.74^{C}	224.27^{DE}	0.0045^{EH}	0.174^{A}	38.38^{BD}	0.0055^{FG}	0.212^{CD}
MAD × Cheese-whey	101.67^{BE}	56.33^{A}	30.33^{B}	211.80^{A}	9.07^{B}	1.07^{B}	51.47^{B}	5.14^{B}	201.20^{EG}	0.0051^{CF}	0.067^{BD}	41.45^{B}	0.0048^{G}	0.053^{F}
TWL × Control	99.33^{DE}	32.66^{G}	16.66^{H}	91.64^{FG}	2.56^{F}	0.42^{GH}	23.09^{HI}	2.31^{HI}	216.57^{DF}	0.0046^{DG}	0.186^{A}	40.31^{BC}	0.0110^{C}	0.438^{AB}
TWL × Cheese-whey	102.17^{BD}	37.33^{F}	23.16^{EF}	129.25^{DE}	4.32^{DE}	0.71^{CD}	26.36^{GH}	2.63^{GH}	181.13^{FG}	0.0055^{AC}	0.061^{CD}	49.85^{A}	0.0080^{D}	0.102^{EF}
LSD	3.25*	2.96*	2.20*	23.81*	1.08*	0.13*	3.32*	0.35*	38.05*	0.0008*	0.049*	8.23*	0.0011*	0.079*

Means showing common letter(s) in a column are non-significant statistically at 5% probability using Duncan Multiple Range Test.

leaf dry weight (0.76 g), plant fresh weight (37.82 g), plant dry weight (3.85 g), specific leaf weight (0.0051 g cm^{-2}), and leaf area ratio (39.81), however, specific leaf area (248.14 cm^2 g^{-1}), leaf weight ratio (0.153), net assimilation rate (0.0098 g g^{-1} d^{-1}), and relative growth rate (0.329 g cm^{-2} d^{-1}) were higher in control plants.

The interaction between the cultivars of snapdragon and substrates showed that all plant growth and flowering attributes were significantly different at 5% level of probability (Table 1). Maximum days to flowering was recorded in snapdragon cultivar Day and Night grown in control (105.67 days) and cheese-whey (103.33 days) substrates whereas minimum days to flowering were counted in Magic Carpet in control (83.69 days) and cheese-whey (84.83 days) substrates. Maximum plant height (59.01 cm), number of leaf per plant (32.66), leaf area (220.94 cm^2), leaf fresh weight (10.33 g), leaf dry weight (1.32 g), plant fresh weight (55.09 g), and plant dry weight (5.51 g) were calculated in cultivar Day and Night grown in cheese-whey amended substrate. Snapdragon cultivar Madame Butterfly grown in cheese-whey amended substrate was statistically at par with cultivar Day and Night regarding plant height (56.33 cm) and leaf area (211.80 cm^2) traits. Cultivar Magic Carpet raised in control substrate had highest specific leaf area (319.09 cm^2 g^{-1}), net assimilation rate (0.0199 g g^{-1} d^{-1}), and relative growth rate (0.506 g cm^{-2} d^{-1}). The specific leaf area (311.42 cm^2 g^{-1}) of cultivar Illumination grown in the similar substrate was statistically alike with Magic Carpet. However, specific leaf weight parameter was maximum (0.0063 g cm^{-2}) in cultivar Antiquity Sunset followed by cultivar Day and Night (0.0061 g cm^{-2}) grown in the cheese-whey substrate. Four snapdragon cultivars grown in control substrate, Antiquity Sunset (0.197), Day and Night (0.207), Madame Butterfly (0.174), and Twilight (0.186) statistically behaved alike regarding leaf weight ratio parameter. Data regarding leaf area ratio was significantly increased when snapdragon cultivars were grown in cheese-whey amended substrate, however, it was higher in cultivar Twilight (49.85).

The combined data of seven snapdragon cultivars and two substrates were analyzed to find out the correlation among various plant growth attributes using Spearman's method (Fig. 1). A highly significant positive correlation was found among plant height, number of leaf per plant, leaf area, leaf fresh weight, leaf dry weight, plant fresh weight, and plant dry weight attributes. Correlation coefficient of plant height with number of leaf per plant, leaf area, leaf fresh weight, leaf dry weight, plant fresh weight, and plant dry weight ranged from 0.82 to 0.96. It was 0.90 to 0.96 when number of leaf per plant was correlated with plant height, leaf area, leaf fresh weight, leaf dry weight, plant fresh weight, and plant dry weight. Leaf area was significantly increased with the increased in plant height (0.95), number of leaf per plant (0.97), leaf fresh weight (0.98), leaf dry weight (0.92), plant fresh weight (0.97), and plant dry weight (0.96) attributes. The correlation coefficient ranges of leaf fresh weight, leaf dry weight, plant fresh weight, and plant dry weight within the above group of attributes were 0.88−0.98, 0.82−0.96, 0.84−0.99, and 0.82−99, respectively. However, specific leaf area, net assimilation rate, and relative growth rate parameters were significantly negative correlated to days to flowering, plant height, number of leaf per plant, leaf area, leaf fresh weight, leaf dry weight, plant fresh weight, plant dry weight, specific leaf weight, and leaf area ratio. Similar negative trend was found when specific leaf weight and leaf area ratio correlated with specific leaf area, net assimilation rate, and relative growth rate traits.

The findings of this study revealed that the cheese-whey amended substrate did not influence time of flowering. However, the difference in the said parameter was cultivar dependent. Snapdragon is categorized as facultative long day plant (Baloch *et al.,* 2012) and the floral initiation is responsive to photoperiod (Munir *et al.,* 2017) and light intensity (Munir *et al.,* 2004). Therefore, it is assumed that the amended substrate did not affect floral time and it was the cultivars' photo-sensitive response to the prevailing light condition that is why they can be grouped into early (Magic Carpet), mid (Chuckles), and late (Antiquity Sunset, Day and Night, Illumination, Madame Butterfly, and Twilight) flowering cultivars (Adams *et al.,* 2003).

The results obtained from the present study suggested that the substrate amended with cheese-whey significantly increased plant growth and development attributes compared to control in snapdragon. However, the difference among cultivar regarding these parameters was due to the difference in genotypes. Desirable plant height can be acquired through biological, physical, and chemicals methods (Baloch *et al.,* 2013; Munir and Alhajhoj, 2017; Demir and Çelikel, 2019). The positive influence of leaf mold substrate was reported in snapdragon cultivar Orchid Rocket that significantly enhanced plant height, number of leaves, stem, leaf, and plant fresh, and dry weight (Naz *et al.,* 2013). Similarly, Rainbow and Wilson (1998) reported that the substrate from green waste significantly enhanced growth of snapdragon, stock and tomato plants. In the present study, number of leaf per plant, leaf area, fresh and dry weights of leaf and plant, specific leaf weight, and leaf area ratio were significantly higher when plants were grown in cheese-whey amended substrate. It could be due to the maximum nutrient availability in the cheese-whey amended substrate, therefore, plants utilized much of the nutrients to produce maximum assimilates. This assumption appears logical while looking at the plant fresh and dry weight data. It is reported that the whey application improves the physical soil properties and provides essential micro-nutrients to the plant that enhance plant growth and development (Lehrsch and Robbins, 1996; Robbins and Lehrsch, 2020). Similarly, the vigor (height and weight) of wheat, soybean, and broccoli plants was significantly enhanced by the application of whey (Grosu *et al.,* 2012).

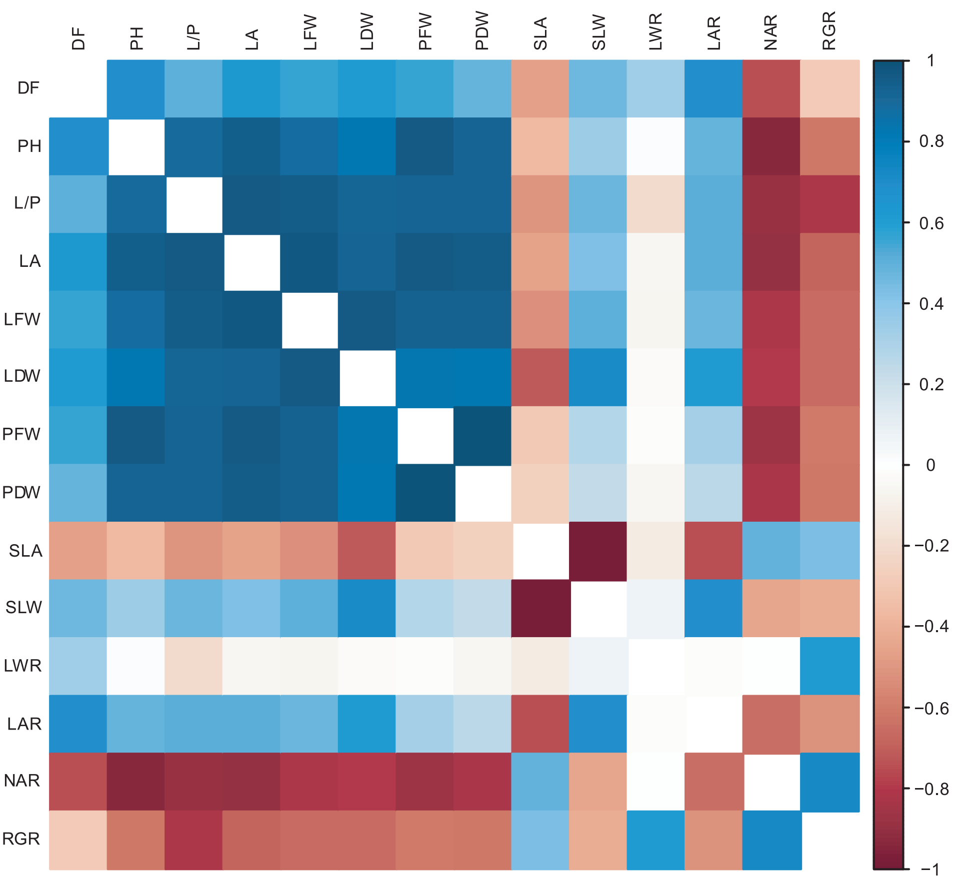

Fig. 1. Correlation test among various growth attributes in the seven snapdragon cultivars and two substrates. A total of 84 biological replicates were averaged. DF, days to flowering (days), PH, plant height (cm), L/P, number of leaf per plant, LA, leaf area (cm^2), LFW, leaf fresh weight (g), LDW, leaf dry weight (g), PFW, plant fresh weight (g), PDW, plant dry weight (g), SLA, specific leaf area (cm^2 g^{-1}), SLW, specific leaf weight (g cm^{-2}), LWR, leaf weight ratio, LAR, leaf area ratio, NAR, net assimilation rate (g g^{-1} d^{-1}), and RGR, relative growth rate (g cm^{-2} d^{-1})

It is concluded that cheese-whey can be recycled into useful soil conditioner to improve the properties of substrate that subsequently enhance plant growth and development traits.

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Received: January, 2023; Revised: March, 2023; Accepted: April, 2023