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Studies on the Impact of Various Cultivation Practices on Phytochemical Parameters of Broccoli

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Abstract

The experiment on studies on the impact of various cultivation practices on phytochemical parameters of Broccoli (*Brassica oleracea* var. *italica* L.) was conducted during the *rabi* season of 2021–2022 with 3 transplanting dates (8th October, 28th October and 18th November 2021) followed by 3 subsequent harvesting dates (29th January, 8th March and 19th February, 2022) at the Research Farm, Department of Environmental Science, College of Forestry, Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India. After harvesting the crop different phytochemical parameters were analysed for studying the effects of different treatments. The highest content of various phytochemical compounds like Total Soluble Solids (TSS), carotenoids, total phenols, glucosinolates, ascorbic acid, protein, total sugar, total chlorophyll, antioxidants, titratable acidity, anthocyanin, total lipids, etc. was reported in crop sown in the mid-season during the first week of October and followed by transplanting at the end of the same month. The mulching and irrigation practices also led to have increased concentration of these biochemical components in the Broccoli. In the case of mid-season transplanted, mulched and irrigated broccoli, the various biochemical compounds like carotenoids, total phenols, glucosinolates, ascorbic acid, protein, chlorophyll, anthocyanins and total antioxidants were reported 26.32, 20.13, 10.27, 58.42, 16.56, 27.03, 28.70 and 16.76% respectively higher than the control samples and these cultivation practices were further recommended for the quality production of broccoli.

Keywords: Antioxidant, biochemical compounds, broccoli, mulching, sowing, transplanting

1. Introduction

Presently, the horticulture sector contributes around 30% of the country's agricultural GDP from 8.5% of the total cropped area. The diverse agro-climatic conditions and rich biodiversity of the country facilitate the production of a wide range of horticultural crops (Sharma and Thakur, 2022). Vegetables are rich sources of major nutrients like carbohydrates, proteins, fats, minerals and vitamins (Prashanthi et al., 2022). Recently, clinical trials have suggested that broccoli may contribute to the prevention of severe COVID-19 symptoms (Bousquet et al., 2021).

The name "broccoli" is a derivation of the Italian "*broccolo*", which denotes the flowering top of a cabbage (Li et al., 2019). Broccoli belonging to the family *Brassicaceae* is an important cole vegetable crop. China is one of the major countries in broccoli production and it is also grown in other countries like the USA, France, Italy and Spain (Singh et al., 2014). In India, it is mainly cultivated in the hilly areas of Himachal Pradesh, Uttar Pradesh, Jammu and Kashmir, Nilgiri hills, and Northern plains of India with an annual production of 88,40,000 tonnes and productivity of 19.30 t ha^{-1} (Saha et al., 2023). Broccoli is a rich source of various nutrients like fibre, anti-oxidants, vitamins, minerals and phytonutrients which are of prime importance towards healthy immune and helps in prevention of various diseases (Mal et al., 2015; Thakur et al., 2019 and Moniruzzaman et al., 2020).

Research on various cultural practices like sowing time, mulching, irrigation, etc., is needed for the production of highly nutritious crops. The sowing and transplanting date in

the case of vegetables including broccoli is one of the most important factors affecting growth and the phytochemical profile of the final produce (Saha et al., 2023). Interaction between the date of planting and spacing was significant with respect to head yield per hectare (Saha et al., 2023). The control was superior in quality traits such as dry matter, total sugar, β-carotene and vitamin-C content (Verma et al., 2018).

Mulching is one of the very important cultivation practices which act as an efficient means of conserving soil moisture by acting as a surface barrier to check evaporation and it also helps in insulation against very low or high-temperature conditions of the environment. The best quality broccoli heads are produced when the day temperature is between 25°C and 26°C and the night temperature is between 15–16°C (Suthar and Bola, 2017).

The most commonly used mulching material is black polyethylene mulch as it prevents or delays weed growth due to their inhibition along with an increase in the yield and earliness of the spring season-grown vegetables (Dittmar and McRae, 2012). Further, it also acts as a barrier to soil erosion and enhances root growth which ultimately facilitates the higher uptake of nutrients from the soil (Kumara and Dey, 2011). Mana et al. *(*2022) studied the effect of different mulches and reported a significant effect on the yield of broccoli, minimum soil temperature fluctuation, soil moisture, and organic carbon content. The quality of the produce is highly affected concerning the irrigation water provided to the crop. Yield response factor and water-yield production function suggested the potential yield decrease with increased deficit irrigation (Patra et al., 2022). So, keeping in view, the studies were carried out on the effect of various cultivation practices like transplanting time, mulching and irrigation conditions on the various phytochemical parameters of the broccoli.

2. Materials and Methods

2.1. Experimental area and geographical conditions

The present field experiment on broccoli crop was conducted at the Research Farm of the Department of Environmental Science, College of Forestry, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India during the rabi season with 3 transplanting dates (8th October, 28th October and 18th November 2021) followed by 3 subsequent harvesting dates (29th January, 8th March and 19th February, 2022) of 2021–22. The climate of the area is sub-tropical to sub-temperate and sub-humid characterized by cold winters and experiences distinguished major seasons in the year. The area is situated at 30.86 ^{o}N latitude and 77.17^{o}E longitude an altitude of 1275 m above the mean sea level. The annual normal of maximum and minimum temperature, relative humidity, and rainfall of the area is 25.3^{o}C, 11.4^{o}C, 61%, and 111.9 cm, respectively.

2.2. Experimental methodology

The soils of the experimental field were deep brown in color with a loam texture. The Broccoli (*Brassica oleracea* var italica L.) crop was sown in the main season, mid-season, and late season in the nursery on 12th September, 2021, 02nd October, 2021, and 23rd October, 2021, respectively. The crop was transplanted on three different dates (8th October, 28th October and 18th November, 2021) with and without mulching under irrigated and rainfed conditions during the *rabi* seasons of 2021–22 (Table 1). The UV-resistant black plastic mulch sheet 30-micron covered about 4.05 m^2 area was laid in the plots. No fertilizers and pesticides were used in the present study. Manure completely decomposed (FYM) was applied 10 days before transplanting at the rate of 10 kg bed^{-1}. FYM was applied as per the package of practices for vegetable crops, Directorate of Extension Education, Dr Y S Parmar University of Horticulture and Forestry, Nauni, Solan (HP).

Table 1: Treatment details with respect to the date of sowing, mulching and irrigation conditions

Sl. No.	Code	Treatments
1.	-	Control
2.	$T_1M_1I_1$	Main season transplanting (8th Oct) +Mulch+Irrigation
3.	$T_1M_1I_2$	Main season transplanting (8th Oct) +Mulch+Rainfed
4.	$T_2M_1I_1$	Mid-season transplanting (28th Oct) +Mulch+Irrigation
5.	$T_2M_1I_2$	Mid-season transplanting (28th Oct) +Mulch+Rainfed
6	$T_3M_1I_1$	Late season transplanting (18th Nov) +Mulch+Irrigation
7.	$T_3M_1I_2$	Late season transplanting (18th Nov) +Mulch+Rainfed
8.	$T_1M_2I_1$	Main season transplanting (8th Oct)+No Mulch+Irrigation
9.	$T_1M_2I_2$	Main season transplanting (8th Oct)+No Mulch+Rainfed
10.	$T_2M_2I_1$	Mid-season transplanting (28th Oct)+No Mulch+Irrigation
11.	$T_2M_2I_2$	Mid-season transplanting (28thh Oct)+No Mulch+Rainfed
12.	$T_3M_2I_1$	Late season transplanting (18th Nov)+No Mulch+Irrigation
13.	$T_3M_2I_2$	Late season transplanting (18th Nov)+No Mulch+Rainfed

T: Transplanting; M: Mulching, I: Irrigation

2.3. Determination of biochemical parameters

The edible portion of the broccoli was analyzed for the following various phytochemical/quality parameters viz. Total Soluble Solids, carotenoids, total phenols, glucosinolates, ascorbic acid, protein, total sugar, total chlorophyll, antioxidants, titratable acidity, anthocyanins, total lipids, etc.

The Total Soluble Solids (TSS as °Brix) were determined with the aid of an Erma Hand refractometer in the range 0-32°B (Model–RHB 32ATC). The carotenoid content was estimated by the method of Davies and Goodwin (1976) and expressed as µgg^{-1} of the sample. The method of Bray and Thorpe (1954) was used for the estimation of total phenol in the broccoli samples with a standard curve of catechol. The determination of glucosinolate content in the edible portion of broccoli was estimated as per the method of Tholen et al. (1989). The titratable acidity, ascorbic acid, total sugars, anthocyanin and chlorophyll content in the edible portion of broccoli were estimated by using the method given by Ranganna et al. (2009). The protein content in the edible portion of broccoli was estimated according to Lowry's method. The Williams method by Dawidowicz et al. (2012) was used for the determination of total antioxidant activity in the edible portion of broccoli. The total lipids in the samples were determined by the method given by Folch et al. (1957).

2.4. Statistical analysis

The parameters on various physico-chemical characteristics of broccoli were replicated three times and further analysed by three factorial completely randomized designs.

3. Results and Discussion

The results pertaining to the effects of mulching, date of sowing and irrigation on various phytochemical parameters of broccoli have been given in Table 2. Among different dates of transplanting the significantly highest TSS was observed in treatment T_2 (12.30°B). The TSS content was recorded higher in the mulched treatments (11.91°B) as compared to the non-mulched treatments (10.78%). The broccoli grown under irrigated conditions has a higher TSS (11.51°B) whereas lower (11.18°B) under un-irrigated conditions.

The carotenoids and total phenol content were highest in treatment T_2 which has been reported as 1.82 and 1.76 mg 100 g^{-1} of broccoli. The same parameters were observed in higher quantities in the case of mulched and irrigated samples. The glucosinolates content was recorded in the range of 2.66–2.78 µ mole 100 g^{-1}, highest in the treatment T_2 whereas in the case of mulching and irrigation treatments, the glucosinolates content was nearly similar. A very high amount of ascorbic acid content as 85.72 mg 100 g^{-1} has been reported during the mid-season transplanting time (T_2) with respect to 66.26 and 46.01 mg 100 g^{-1} in the main season and late seasons, respectively. The mulching and irrigation treatments also recorded a very high amount of ascorbic acid content 72.38 and 72.36 mg 100 g^{-1} as compared to un-mulched (59.61 mg 100 g^{-1}) and un-irrigated samples (59.63 mg 100 g^{-1}) respectively.

The planting time, mulching and irrigation practices have little effect on the protein and total sugar content of the broccoli, but slightly higher values were recorded in treatment T_2 (3.74 and 2.66%), mulched (3.63 and 2.62%) and irrigated samples (3.62 and 2.61%). Among different dates of transplanting the significantly highest chlorophyll content was observed in treatment T_2 (0.89 mg 100 g^{-1}), whereas, while studying the effect of mulching and irrigation a slightly higher chlorophyll content was recorded in the mulched treatments (0.86 mg100 g^{-1}) and irrigated conditions (0.86 mg 100 g^{-1}) with respect to un-mulched and rainfed treatments. A very high number of total antioxidants as 3.80 µ mole 100 g^{-1} has been reported during the mid-season transplanting time (T_2) with respect to 3.39 and 3.07 µ mole 100 g^{-1} in the main season and late seasons, respectively. The mulching and irrigation treatments also recorded a very high amount of total antioxidant content at 3.50 and 3.48 µ mole 100 g^{-1} as compared to un-mulched (3.34 µ mole 100 g^{-1}) and un-irrigated samples (3.37 µ mole 100 g^{-1}) respectively.

The titratable acid content was highest (0.71%) in the broccoli grown during the mid-season transplanting time (T_2) as compared to the main season (0.55%) and late season (0.29%). The titratable acid content was recorded higher in the mulched treatments (0.58%) as compared to the non-mulched treatments (0.45%). The broccoli grown under irrigated conditions has a higher titratable acidity (0.58%) whereas lower (0.45%) under un-irrigated conditions. The anthocyanin content of the broccoli grown during the mid-season transplanting time (T_2) was the highest (193.65 mg 100 g^{-1}) with respect to 176.30 and 158.92 mg 100 g^{-1} in main season and late season crop, respectively. The mulching and irrigation treatments also recorded a very high amount of anthocyanin content 181.55 and 179.14 mg 100 g^{-1} as compared to un-mulched (171.03 mg 100 g^{-1}) and un-irrigated samples (173.44 mg 100 g^{-1}) respectively. Among different dates of transplanting the significantly highest total lipid content was observed in treatment T_2 (269.51 mg 100 g^{-1}), whereas, while studying the effect of mulching and irrigation a slightly higher total lipids content was recorded in the mulched treatments (257.82 mg 100 g^{-1}) and irrigated conditions (253.02 mg 100 g^{-1}) as compared to un-mulched (243.99 mg 100 g^{-1}) and un-irrigated crop (248.79 mg 100 g^{-1}).

The various phytochemical parameters were recorded higher in the mulched treatment as compared to the un-mulched crop. The uncovered soil i.e. without any mulching practices undergoes various stress conditions which generally results in poor biochemical characteristics of the crop. The mulching treatment provides favourable environmental rhizosphere resulting in better plant growth with higher content of biochemical parameters as observed in the same studies too. Similarly, broccoli grown under irrigated conditions has a higher nutritional profile in terms of biochemical

Table 2: Effect of mulching, date of sowing, and irrigation on phytochemical parameters of Broccoli

Treatment	Biochemical parameters											
DT	TSS	Ca	TP	Gl	AA	Pr	TS	Ch	TA	Ti	An	TL
T_1	11.71	1.63	1.71	2.78	66.26	3.60	2.61	0.84	3.39	0.55	176.30	252.15
T_2	12.30	1.82	1.76	2.83	85.72	3.74	2.66	0.89	3.80	0.71	193.65	269.51
T_3	10.02	1.44	1.42	2.66	46.01	3.60	2.41	0.76	3.07	0.29	158.92	231.05
SEm±	0.13	0.01	0.01	0.00	0.50	0.02	0.0.1	0.01	0.04	0.01	0.58	0.73
CD (*p*=0.05)	0.38	0.02	0.02	0.01	1.47	0.02	0.02	0.02	0.13	0.02	1.71	2.15
M_1 (Mulching)	11.91	1.70	1.72	2.79	72.38	3.63	2.62	0.86	3.50	0.58	181.55	257.82
M_2 (No Mulching)	10.78	1.57	1.54	2.72	59.61	3.66	2.50	0.80	3.34	0.45	171.03	243.99
SEm±	0.11	0.01	0.00	0.00	0.41	0.01	0.01	0.00	0.04	0.00	0.48	0.60
CD (*p*=0.05)	0.31	0.01	0.01	0.01	1.20	0.02	0.02	0.01	0.11	0.01	1.40	1.76
I_1 (Irrigation)	11.51	1.69	1.67	2.78	72.36	3.62	2.61	0.86	3.48	0.58	179.14	253.02
I_2 (No irrigation)	11.18	1.57	1.60	2.73	59.63	3.68	2.51	0.80	3.37	0.45	173.44	248.79
SEm±	0.11	0.01	0.00	0.00	0.41	0.01	0.01	0.00	0.06	0.00	0.48	0.60
CD (*p*=0.05)	0.31	0.01	0.01	0.01	1.20	0.02	0.02	0.01	0.18	0.01	1.40	1.76
Interaction (T×M)												
T_1M_I	12.06	1.69	1.80	2.81	72.29	3.55	2.70	0.87	3.53	0.61	179.49	259.92
T_2M_1	13.29	1.90	1.89	2.87	94.60	3.70	2.69	0.92	3.95	0.80	202.33	279.56
T_3M_1	10.38	1.49	1.48	2.69	50.26	3.65	2.48	0.77	3.04	0.33	162.83	233.98
T_1M_2	11.36	1.57	163	2.75	60.22	3.66	2.51	0.82	3.26	0.49	173.11	244.39
T_2M_2	11.31	1.74	1.64	2.78	76.85	3.77	2.63	0.85	3.65	0.62	184.96	259.46
T_3M_2	9.67	1.39	1.36	2.62	41.76	3.54	2.35	0.74	3.11	0.25	155.01	228.12
SEm±	0.18	0.01	0.01	0.01	0.71	0.01	0.01	0.01	0.06	0.01	0.83	1.04
CD (*p*=0.05)	0.54	0.03	0.02	0.01	2.07	0.03	0.03	0.02	0.18	0.02	2.42	3.04
Interaction (T×I)												
T_1I_1	11.91	1.72	1.73	2.81	75.43	3.52	2.65	0.88	3.42	0.64	179.17	257.39
T_2I_1	12.54	1.88	1.81	2.85	91.77	3.69	2.71	0.90	3.81	0.77	197.40	269.50
T_3I_1	10.08	1.47	1.45	2.67	49.87	3.64	2.46	0.77	3.20	0.33	160.85	232.17
T_1I_2	11.51	1.54	1.69	2.74	57.08	3.69	2.56	0.80	3.36	0.46	173.43	246.92
T_2I_2	12.06	1.77	1.72	2.80	79.67	3.74	2.61	0.87	3.79	0.65	189.89	269.51
T_3I_2	9.97	1.41	1.39	2.64	42.15	3.56	2.37	0.75	2.95	0.25	156.99	229.93
SEm±	0.18	0.01	0.01	0.01	0.71	0.01	0.01	0.01	0.06	0.01	0.83	1.04
CD (*p*=0.05)	NS	0.03	0.02	0.01	2.07	0.03	NS	0.02	0.18	0.02	NS	3.04
Interaction (M×I)												
M_1I_1	12.02	1.74	1.75	2.82	78.03	3.54	2.70	0.87	3.60	0.64	185.47	262.33
M_2I_1	10.99	1.64	1.59	2.74	66.69	3.69	2.52	0.83	3.35	0.52	172.81	243.71
M_1I_2	11.79	1.65	1.69	2.76	66.74	3.72	2.55	0.84	3.40	0.52	177.63	253.31
M_2I_2	10.56	1.50	1.50	2.70	52.53	3.63	2.51	0.77	3.33	0.38	169.25	244.27
SEm±	0.15	0.01	0.01	0.00	0.58	0.01	0.01	0.01	0.05	0.01	0.67	0.85
CD (*p*=0.05)	NS	0.02	0.02	0.01	1.69	0.02	0.03	0.02	NS	0.02	1.98	2.48

Treatment	Biochemical parameters											
DT	TSS	Ca	TP	Gl	AA	Pr	TS	Ch	TA	Ti	An	TL
Interaction (T×M×I)												
Control	11.36	1.52	1.59	2.63	61.20	3.26	2.51	0.74	3.40	0.48	160.45	246.78
$T_1M_1I_1$	12.28	1.78	1.82	2.86	81.32	3.34	2.76	0.91	3.57	0.70	184.26	268.77
$T_1M_1I_2$	12.00	1.60	1.77	2.76	63.26	3.76	2.65	0.82	3.48	0.52	174.72	251.07
$T_1M_2I_1$	11.70	1.66	1.64	2.76	69.54	3.69	2.55	0.85	3.27	0.58	174.08	246.01
$T_1M_2I_2$	11.02	1.48	1.62	2.73	50.91	3.62	2.47	0.78	3.24	0.40	172.13	242.77
$T_2M_1I_1$	13.57	1.92	1.91	2.90	96.95	3.58	2.78	0.94	3.97	0.82	206.50	283.09
$T_2M_1I_2$	13.02	1.89	1.87	2.84	92.25	3.58	2.60	0.91	3.93	0.77	198.16	276.02
$T_2M_2I_1$	11.51	1.84	1.72	2.80	86.60	3.80	2.65	0.86	3.65	0.72	188.30	255.92
$T_2M_2I_2$	11.10	1.64	1.56	2.76	67.10	3.75	2.62	0.84	3.65	0.52	181.62	263.00
$T_3M_1I_1$	10.39	1.53	1.50	2.70	55.81	3.71	2.55	0.75	3.28	0.39	165.66	235.13
$T_3M_1I_2$	10.36	1.45	1.44	2.67	44.70	3.60	2.40	0.79	2.79	0.28	160.00	232.83
$T_3M_2I_1$	9.77	1.41	1.39	2.65	43.93	3.57	2.36	0.78	3.12	0.27	156.04	229.21
$T_3M_2I_2$	9.57	1.37	1.33	2.60	39.59	3.51	2.33	0.70	3.11	0.23	153.99	227.03
SEm±	0.26	0.01	0.01	0.01	1.00	0.01	0.02	0.01	0.09	0.01	1.17	1.47
CD (*p*=0.05)	NS	0.04	0.03	0.02	2.93	0.04	0.04	0.03	NS	0.03	NS	4.30

DT: Date of Transplanting; TSS: TSS (°B); Ca: Carotenoids (mg 100 g^{-1}); TP: Total phenols (mg 100 g^{-1}); Gl: Glucosinolates (µ mole 100 g^{-1}); AA: Ascorbic acid (mg 100 g^{-1}); Pr: Protein (%); TS: Total sugar (%); Ch: Chlorophyll (mg 100 g^{-1}); TA: Total antioxidants (µ mole 100 g^{-1}); Ti: Titratable acidity (%); An: Anthocyanin (mg 100 g^{-1}); TL: Total lipids (mg 100 g^{-1})

compounds. Water plays a vital role in the availability of nutrients from the soil to the crop and thereby enhancing the photosynthesis process, translocation of assimilates, metabolism and conversion efficiency of the crop (Ali and Akmal, 2020).

The overall effect of planting time, mulching and irrigation practices had a significant effect on various phytochemical constituents of broccoli. The carotenoid content was recorded highest (1.92 mg 100 g^{-1}) in mid-season transplanted, mulched and irrigated broccoli (19.45% higher than control) which was closely followed by mid-season transplanted, mulched and rainfed crops. The significantly highest total phenols (1.91 mg 100 g^{-1}), glucosinolates (2.90 µ mole 100 g^{-1}) and ascorbic acid content (96.95 mg 100 g^{-1}) were also recorded as highest in mid-season transplanted mulched and irrigated broccoli which was 20.13, 10.27 and 58.42% higher than the control broccoli samples respectively. The protein content was found highest in irrigated mid-season transplanting crop without mulching (3.80%). In mid-season transplanted, mulched and irrigated broccoli the total sugar and titratable acid content was also recorded highest (2.78 and 0.82%) which was 10.76 and 70.83% higher with respect to the control samples. The significantly highest chlorophyll content (0.94 mg 100 g^{-1}) and total lipids (283.09 mg 100 g^{-1}) were also recorded as highest in mid-season transplanted mulched and irrigated broccoli which was 27.03 and 14.71% higher than the control broccoli samples. However, the combined effect of planting time, mulching and irrigation practices on TSS, total antioxidants and anthocyanins was found to be non-significant but still, it was recorded highest in mid-season transplanted, mulched and irrigated crops. Mashkey et al. (2023) and Mana et al. (2022) have also reported significantly higher quality parameters in the case of mulched broccoli samples.

4. Conclusion

The various phytochemical compounds like Total Soluble Solids (TSS), carotenoids, total phenols, glucosinolates, ascorbic acid, protein, total sugar, total chlorophyll, antioxidants, titratable acidity, anthocyanin, total lipids, etc. was reported highest in crop sown in the mid-season during the first week of October and followed by transplanting at the end of the same month. The mulched and irrigated broccoli samples were having a better nutritional profile in terms of various phytochemical compounds.

5. Acknowledgment

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6. References

Ali, M., Akmal, M., 2020. Morphophysiological traits, biochemical characteristic and productivity of wheat under water and nitrogen-colimitation: pathways to

improve water and N uptake. In: Fahad, S., Saud, S., Chen, Y., Wu, C., Wang, D. (Eds.). Abiotic Stress in Plants. IntechOpen Limited, London, 1–28.

Bousquet, J., Moing, V.L., Blain, H., Czarlewski, W., Zuberbier, T., Torre, R.D.L., Lozano, N.P., Reynes, J., Bedbrook, A., Cristol, J.P., Cruz, A.A., Fiocchi, A., Haahtela, T., Iaccarino, G., Klimek, L., Kuna, P., Melén, E., Mullol, J., Samolinski, B., Valiulis, A., Anto, J.M., 2021. Efficacy of broccoli and glucoraphanin in COVID-19: From hypothesis to proof-of-concept with three experimental clinical cases. World Allergy Organization Journal 14(1), 100498.

Bray, H.G., Thorpe, W., 1954. Analysis of phenolic compounds of interest in metabolism, In: Glick, D. (Ed.), Methods of biochemical analysis. Interscience Publisher, New York, 27–52.

Dawidowicz, A.L., Wianowska, D., Olszowy, M., 2012. On practical problems in estimation of antioxidant activity of compounds by DPPH method (Problems in estimation of antioxidant activity). Food Chemistry 131(3), 1037–1043.

Davies, B.H., Goodwin, T.W., 1976. Chemistry and biochemistry of plant pigments. Carotenoids 2, 38–165.

Dittmar, P.J., McRae, A.W., 2012. Weed Management, IFAS Extension Bulletin, University of Florida.

Folch, J., Lees, M., Sloane Stanley, G.H., 1957. A simple method for the isolation and purification of total lipids from animal tissues. Journal of Biological Chemistry 226(1), 497–509.

Kumara, S., Dey, P., 2011. Effect of different mulches and irrigation methods on root growth, nutrient uptake, water-use efficiency and yield of strawberry. Scientia Horticulture 27, 318–324.

Li, Z., Mei, Y., Liu, Y., Fang, Z., Yang, L., Zhuang, M., Zhang, Y., Lv, H., 2019. The evolution of genetic diversity of broccoli cultivars in China since 1980. Scientia Horticulturae 250, 69–80.

Mal, D., Chatterjee R., Nimbalkar, K.H., 2015. Effect of vermi-compost and inorganic fertilizers on growth, yield and quality of sprouting broccoli (*Brassica oleracea* L. var. italica Plenck). International Journal of Bio-resource and Stress Management 5(4), 507–512.

Mana, K., Saha, B., Kundu, M.C., 2022. Study of non-woven jute agrotextile mulches on soil water, temperature and nutrient status in root zone in broccoli (*Brassica oleracea* L.) cultivation. International Journal of Bio-resource and Stress Management 13(4), 348–356.

Mashkey, K.M., Chamroy, T., Choudhary, D., Shrivastava, M., Sengupta, J.D., 2023. Effect of integrated nitrogen and mulching on growth, yield and quality characteristics of Broccoli (*Brassica oleracea* var. *italica*) cv. Palam Samridhi. Journal of Advanced Zoology 44(4), 50–59.

Moniruzzaman, M., Khatoon, R., Islam, F., 2020. Vegetative growth, yield and quality of broccoli as influenced by application of gibberellic acid. Bangladesh Journal of Agricultural Research 45(3), 247–259.

Patra, S.K., Poddar, R., Pramanik, S., Gaber, A., Hossain, A., 2022. Crop and water productivity and profitability of broccoli (*Brassica oleracea* L. var. *italica*) under gravity drip irrigation with mulching condition in a humid sub-tropical climate. PLoS ONE 17(3), e0265439. https://doi.org/10.1371/journal.pone.0265439.

Prashanthi, C., Prasad, V.M., Topno, S.E., Vani, K.L., Singh, Y.K., 2022. Performance of different varieties of broccoli (*Brassica Oleracea* var. italica) under Prayagrajagro-climatic condition. International Journal of Environment and Climate Change 12(11), 3003–3009.

Ranganna, S., 2009. Handbook of analysis and quality control for fruits and vegetables. Tata Mc. Graw Hill Publishing Company Limited, New Delhi.

Saha, T., Basfore, S., Choudary, S.R., Sikder, S., Debnath, M.K., 2023. Effect of date of planting and spacing on growth and yield of sprouting Broccoli (*B. oleraceae* (L.) var. italica Plenck) cv. Green Magic. International Journal of Bio-resource and Stress Management 14(7), 1067–1073.

Sharma, K.D., Thakur, A., 2022. Fresh horticultural produce handling and processing for entrepreneurship. In: Singh, D., Devappa, V., Jahagirdar, S., Gautam, H.R., Aggarwal, R. (Eds.), Management of postharvest diseases and value addition of horticultural crops. Today & Tomorrow's Printers and Publishers, New Delhi, 299–307.

Singh, A., Maji, S., Kumar, S., 2014. Effect of biofertilizers on yield and biomolecules of anti-cancerous vegetable broccoli. International Journal of Bio-resource and Stress Management 5(2), 262–268.

Suthar, V., Aravindakshan, K., Bola, P.K., 2017. Effect of sowing date and spacing on growth, yield and quality of broccoli (*Brassica oleracea* var. italica) var. green head. Chemical Science Review and Letters 6(21), 209–212.

Thakur, A., Joshi, V.K., Thakur, N.S., 2019. Immunology and its relation with food components: an overview. International Journal of Food and Fermentation Technology 9(1), 1–16.

Tholen, J.T., Shifeng, S., Truscott, R.J., 1989. The thymol method for glucosinolate determination. Journal of the Science of Food and Agriculture 49(2), 157–165.

Verma, V.K., Jha, A.K., Verma, B.C., Nonglat, D., Chaudhary, P., 2018. Effect of mulching materials on soil health, yield and quality attributes of broccoli grown under the mid-hill conditions. Proceedings of the National Academy of Sciences, India Section B: Biological Sciences 88, 1589–1596. https://doi.org/10.1007/s40011-017-0907-3.