Profile of chlorophylls and carotenoids of wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) microgreens

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Abstract The use of cereal microgreens is increasing because of increased consumer's interest in healthier products. Chlorophyll (Chl) and Carotenoids (Car) are suggested to correlate with health promoting components like phenolics and antioxidant potential of the plant-part. They also play role against clinical conditions like thalassemia and hemolytic anemia and reduce the risk of some chronic diseases, such as cancer, cardiovascular diseases, skin diseases and age-related eye diseases. This study was carried out for the comprehensive profiling of Chl and Car in wheat (*Triticum aestivum* L.), and barley (*Hordeum vulgare* L.) micro-greens between 7 and 16 days on dry basis. Chl and Car content strongly correlated with the number of days of growth. Significantly high correlations existed among Chl a, Chl b, total Chl and total Car with concomitant Chl a/b and Chl/Car ratios. The peaks for the rate of accumulation of pigments were between 7–10 days on wheat and 10–13 days on barley. The maximum content of Chl and Car were 616.63 ± 18.45 mg/100 g DM and 54.80 ± 1.72 mg/100 g DM on day 16 and statistically not significant to variety of grain. The Chl level was slightly lower than Chl rich vegetables like kale and comparable to spinach and Car level was comparable to carrots, which is

higher than most of the daily consumable fruits and vegetables. Further cell-based or in vivo studies of cereal microgreens could be considered to draw more valuable information related to human health.

Keywords Chlorophyll · Carotenoids · Germination · Microgreens · Wheat · Barley

Introduction

The use of young plantlets, 1–2 weeks of age, commonly termed as *microgreens*, is increasing, because of their high concentrations of high value nutrients and health benefits such as prevention of cardiovascular diseases and cancer (Benincasa et al. 2015). The higher nutritional value and health benefits in microgreens are attributed the high concentrations of amino acids, enzymes, vitamins, minerals, phenolics, antioxidants and pigments: chlorophyll (Chl) and carotenoids (Car) (Padalia et al. 2010). Chlorophyll (Chl) and carotenoids (Car) are the two most abundant pigments on earth. Chlorophyll a (Chl a) and Chlorophyll b (Chl b) are the pre-dominant forms of Chl in higher plants that play a key role as primary photosynthetic pigment that allows the plants to absorb energy from light. Car on other hand plays the role in the photo-protection of chlorophyllous pigments (Eldahshan and Singab 2013; Chen and Roca 2018).

Chl due to its similarity with haemoglobin, is believed to produce either heme or globin or both during digestion, and are used in clinical conditions like thalassemia and hemolytic anemia (Padalia et al. 2010). It neutralizes infection, heals wound, overcome inflammation and gets rid of parasitic infection and play their roles in the anti-cancer function by limiting the bioavailability of

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carcinogens (Padalia et al. 2010; Wakeham 2013). Lutein and its stereoisomer zeaxanthin reduce oxidative stress in the retina and protect photoreceptor cells (Battersby 1988). They also reduce the risk of some chronic diseases, such as cancer, cardiovascular diseases, skin diseases and age-related eye diseases (Eldahshan and Singab 2013). Pigments therefore have protective effects against different infectious and chronic diseases.

The Chl and Car contents have been reported to be correlated to physiological stage and influence the photosynthetic activity as per the demand of metabolically active cells (Kohler 1944; Samanta et al. 2017). Significant positive correlations of total Chl and Car contents have also been reported with total phenolics (Filimon et al. 2016; Samanta et al. 2017) and total phenolics with antioxidative potential (Benincasa et al. 2015; Ozkose et al. 2016; Niroula et al. 2019). The study of pigments could therefore be a good indication of the photosynthetic and metabolic activity of the plant part, and the content of bioactive compounds that have protection against various diseases like total phenolics and antioxidative potential of the plant part. Therefore, the aim of this study was to profile the contents of total Chl and Car of wheat and barley micro-greens on DM basis and assess the rate of accumulation of the pigments.

Materials and methods

Reagents

All chemicals and solvent were of analytical grade. The spectrophotometer used was of model GENESYSTM 10S Vis Spectrophotometer from Thermo ScientificTM, Germany.

Sprouting and germination

Seed grade wheat and barley kernels were obtained from Food Research Division, Nepal Agriculture Research Council. The grains were soaked in cold water for 24 h and drained. The soaked grains were spread in indoor trays containing homogenous quality 8 cm thick soil and covered about 1 cm with the same soil. Adequate water was added daily and allowed to grow for 16 days in daylight inside the room. Sprouting and germination were carried out parallel in two blocks with a gap of 16 days between the blocks. The average temperature and relative humidity of the room throughout the study chamber were 19 °C (7–27 °C) and 66% (29–100%), respectively.

Determination of chlorophylls and carotenoids

Accurately weighted 1 g of fresh plant leaf sample was macerated and extracted with 10% (w/v) of 80% acetone. The supernatants were filtered with Whatman no.1 filter paper and volume makeup was done to 50 ml with solvent. The absorbance of solution mixture at corresponding wavelengths were analyzed for Chl a, Chl b and Car content in spectrophotometer, using the Chl equations (Lichtenthaler and Wellburn 1983) and Car equation (Holm 1954) as follows:

$$\text{Chl a} = 12.21 * A_{663} - 2.81 * A_{646}$$

$$\text{Chl b} = 20.13 * A_{646} - 5.03 * A_{663}$$

$$\text{Car} = 4.69 * A_{440.5} - 0.268 * (\text{Chl a} + \text{Chl b})$$

where A refers to the absorbance reading at the corresponding wavelengths (440.5, 646 and 663 nm). They were further expressed as:

$$\frac{\text{mg pigment}}{100 \text{ g DM}} = \frac{\mu\text{g}}{\text{mL}} \times \frac{\text{volume makeup}}{10 \times \text{dry wt of plant (g)}}$$

Results and discussion

Chlorophylls (Chl) content

Residual amount of Chl were observed in wheat (16.82 ± 0.39 mg/100 g DM) and barley (12.66 ± 1.28 mg/100 g DM) seeds. Statistically significant correlation ($r = 0.993$) was found between the Chl content and number of days of growth. This amount significantly increased ($p < 0.05$) with successive days of germination and growth (Table 1 and Fig. 1). The total Chl content between the micro-greens were statistically similar ($p > 0.05$) except day 10 ($p < 0.05$). The significantly high Chl content in wheat micro-greens of day 10 and barley micro-greens in day 13 were because of the accumulation of chlorophylls in wheat triggered between days 7–10 while in barley on days 10–13. The delay in rate of accumulation of pigments in barley grass was the carryover of the delayed germination of barley. When the heights of these micro-greens were measured from the base on day 5, wheat micro-greens were 10.57 ± 0.28 cm while barley micro-greens were only 7.68 ± 0.21 cm. In a similar study of wheat and barley grass, delayed growth of barley grass have also been reported, with significant difference on the height of grasses and no significant difference on day 13 (Niroula et al. 2019).

The Chl contents of day 16 (608.06 ± 14.39 mg/100 g DM for wheat and 625.20 ± 19.11 mg/100 g DM for barley) were similar to the results reported on barley

Table 1 Chl contents, Chl a/b ratio and the rate of Chl accumulation (mean $\pm$ SD) in wheat and barley grasses

Cereal	Day	Chl a (mg/100 g DM)	Chl b (mg/100 g DM)	Chl a/b	Chl (mg/100 g DM)	Chl accumulation (mg/100 g DM/day)
Wheat	0	5.85 $\pm$ 0.24	10.97 $\pm$ 0.39	0.53 $\pm$ 0.03	16.82 $\pm$ 0.39 g	
	7	183.41 $\pm$ 8.36	85.87 $\pm$ 4.48	2.14 $\pm$ 0.04	269.29 $\pm$ 12.68 e	36.07 $\pm$ 1.81 bc
	10	289.70 $\pm$ 10.85	135.41 $\pm$ 5.64	2.14 $\pm$ 0.04	425.11 $\pm$ 16.11 c	51.94 $\pm$ 5.37 a
	13	369.53 $\pm$ 11.42	175.24 $\pm$ 5.01	2.11 $\pm$ 0.04	532.10 $\pm$ 14.62 b	35.66 $\pm$ 4.88 bc
	16	412.72 $\pm$ 10.84	195.37 $\pm$ 4.38	2.11 $\pm$ 0.04	608.06 $\pm$ 14.39 a	25.32 $\pm$ 4.80 d
Barley	0	4.32 $\pm$ 0.38	8.34 $\pm$ 0.93	0.52 $\pm$ 0.03	12.66 $\pm$ 1.28 g	
	7	166.93 $\pm$ 9.99	80.09 $\pm$ 4.87	2.08 $\pm$ 0.03	247.01 $\pm$ 14.76 e	33.48 $\pm$ 2.11 bc
	10	246.14 $\pm$ 8.99	118.50 $\pm$ 4.87	2.08 $\pm$ 0.03	364.65 $\pm$ 13.62 d	39.21 $\pm$ 4.54 b
	13	360.55 $\pm$ 9.12	171.48 $\pm$ 5.13	2.10 $\pm$ 0.03	532.03 $\pm$ 13.94 b	55.79 $\pm$ 4.65 a
	16	425.36 $\pm$ 14.02	199.84 $\pm$ 5.29	2.13 $\pm$ 0.02	625.20 $\pm$ 19.11 a	31.06 $\pm$ 6.37 cd

^aAll means and SD are calculated from 6 samples collected in 2 blocks and 3 replicates per block

Different letters in a column indicate statistical difference among the sample means ($p < 0.05$)

Fig. 1 Chl and 10 $\times$ Car contents and their rate of accumulation in wheat and barley grasses with days of growth. Figure and line of fit obtained by JMP Pro 13

seedling powder (600.6 ± 19.2 mg/100 g) by Meng et al. (2017) and winter wheat grass cultivated in room daylight to the corresponding height by Skoczylas et al. (2018). Skoczylas et al. (2018) reported the Chl content of 250–270 mg/lit of winter wheat grass juice containing 47–57 g/kg DM, which was about half of the same of summer wheat grass juice. The production of pigment increases with light and temperature until optima, beyond which the production is greatly reduced (Beck and Redman 1940). The Chl content is sufficiently high enough to exert potential health benefits in human. Daily consumption of 100–300 mg of Chl have been proven to be beneficial to various health disorders including various types of cancers

in human (Siriwatanametanon 2017). The peak concentration of total Chl was not achieved in the study period, but the rate of accumulation was achieved. Pigments are synthesized in plants to supply the energy by photosynthesis. The peak rate of pigment accumulation is therefore an indication of the maximum activities of biosynthetic enzymes and energy requirement by the cell. The reduced rate of accumulation of Chl after the peak possibly signifies rapid production of phenolics and other antioxidants in the second week of wheat and barley microgreens (Benincasa et al. 2015; Ozkose et al. 2016). The biosynthesis of Chl is reduced/inhibited by increased amount of allelopathic phenolics (Yang et al. 2002). The maximum Chl content in

kale was in third week (Lefsrud et al. 2007) and that in oatgrass before day 24 (approx. 800 mg/100 g) (Kohler 1944).

Chlorophyll (Chl) a/b ratio

The mean Chl a/b ratio in the seeds and micro-greens were 0.53 ± 0.03 and 2.11 ± 0.04 , respectively (Table 1). The ratio in micro-greens was in agreement with previous studies of wheatgrass cultivated in greenhouse (2.47 ± 0.38) (Shah et al. 2017) and in laboratory (2.07) (Wakeham 2013). Our results were lower than the values illustrated in other open field studies, 3.14 in wheatgrass (Wakeham 2013), 2.9–3.7 in wheatgrass (Skoczylas et al. 2018), 3.2–3.35 in barley grass (Januskaitiene and Klepeckas 2015), and 2.3–2.8 in crops grown in shades and low-light (Lichtenthaler 2007). The high Chl a/b ratio has been associated with the higher level of irradiance or the sunlight (Lichtenthaler 2007) and temperature (Haldimann 1999). This low value of Chl a/b ratio in present study was due to the growth of young grasses in indoor daylight cultivation in winter. Recent studies have suggested that Chl b is more resistive to the degradation during high temperature treatment and storage (Okpalanma and Ojimekwe 2018) and in vitro digestion suggesting potentially high enterocytic absorption (Chen and Roca 2018). Microgreens grown in daylight having low Chl a/b ratio are therefore more bioaccessible than those in sunlight that have higher Chl a/b ratio.

Carotenoids (Car) content

The Car content in the seeds (0.42 ± 0.03 mg/100 g of wheat and DW 0.79 ± 0.04 mg/100 g DW of barley) were replicating to previous studies (Paznocht et al. 2018). The correlation ($r = 0.987$) between the Car content and number of days of growth were statistically significant ($p < 0.05$). The total Car contents in the micro-greens were significantly increased ($p < 0.05$) with the days of growth and reached maximum on day 16 (Table 2 and Fig. 1). The Car contents in wheat micro-greens were significantly more ($p < 0.05$) than that of barley up to day 10, but no significant differences were on days 13 and 16. This was because of the maximum rate of accumulation of Cars in wheat micro-greens showed before day 10 and that in barley on days 10–13, similar to the case of total Chl as discussed previously. The total Car content obtained on day 16 (53.36 ± 1.81 mg/100 g DM for wheat micro-greens and 56.08 ± 1.83 for barley micro-greens) were less than the findings 57.5–105 mg/lit of wheat grass juice containing 47–57 g/kg DM reported by Skoczylas et al. (2018) and 91.7 mg/kg fresh weight (dark) and 180.5 mg/kg fresh weight (light) in the wheatgrass reported by Wolf (1963).

The peak concentration of total Car were not achieved in the study period, but the rate of accumulation reached the peak and started to fall indicating an upcoming peak. Lefsrud et al. (2007) reported the maximum lutein content in kale in between 7 and 14 days and the maximum carotene and Cars content in kale was in between 14 and 21 days. Kohler (1944) also reported that the Car content in dehydrated oat grass on day 30 (approx. 60 mg/100 g) decreased in successive days of growth. Lutein and other xanthophylls are the major carotenoids in the young leaves under low light and shade conditions (Lichtenthaler 2007; Yoon et al. 2012). These xanthophylls are more preferred by the retinal cells (During et al. 2008) and have higher bioaccessibility at low concentration of carotenes (Zaripheh and Erdman 2002) than the microgreens grown in sunlight or higher irradiance with abundant β -carotene (Wolf 1963; Lichtenthaler 2007).

Chl/Car ratio

The total Chl/Car ratio in present study (11.18 ± 0.72) was in accordance to the previous greenhouse studies in barley grass (Simova-stoilova et al. 2001), wheat grass (Ozkose et al. 2016) and in 8 sweet basil cultivars (Kopsell et al. 2005). Present values are in accordance to the principle that the chl/car ratio in high light irradiance leaves is lower (3.6–4.6) as compared to shade and low-light leaves (4.9–7.0) (Rosevear et al. 2001; Lichtenthaler 2007). Total Chl/Car ratios could be a good indicator for evaluating environmental stress or damage of photosynthetic apparatus and senescence of plants (Filimon et al. 2016). Young plants inherently have high value of Chl/Car ratio which decreases subsequently with age (Simova-Stoilova et al. 2001) and this ratio may be doubled at low light conditions due to considerably low amount of carotenoids specifically carotenes (Rosevear et al. 2001). Hence, a high Chl/Car ratio signifies young microgreens grown in low irradiance i.e. daylight with very low amount of carotenes. High Chl/Car ratio is therefore beneficial because of high proportion of xanthophylls which have are preferred by retinal cells and have high bioaccessibility in the low concentration of carotenes (Zaripheh and Erdman 2002; During et al. 2008).

Correlation between the pigments

A highly significant correlation among the pigments Cl a, Chl b, total Chl and Car were observed (Table 3). This implies that with an increase in one of the pigment, there was simultaneous increase in other pigments. Kopsell et al. (2005) also reported a positive correlation between the Chl and Car content in eight sweet basil cultivars grown both greenhouse and open field. Ndukwe et al. (2016) also

Table 2 Car contents, the rate of Car accumulation and Chl/Car ratio in wheat and barley grasses (mean $\pm$ SD)

Cereal	Day	Car (mg/100 g DM)	Car accumulation (mg/100 g DM/day)	Chl/Car
Wheat	0	0.42 $\pm$ 0.03 g		40.25 $\pm$ 3.73
	7	25.75 $\pm$ 1.13 e	3.62 $\pm$ 0.16 b	10.47 $\pm$ 0.59
	10	40.85 $\pm$ 2.01 c	5.03 $\pm$ 0.67 a	10.43 $\pm$ 0.65
	13	47.45 $\pm$ 1.55 b	2.20 $\pm$ 0.52 cd	11.22 $\pm$ 0.49
	16	53.36 $\pm$ 1.81 a	1.97 $\pm$ 0.60 cd	11.40 $\pm$ 0.37
Barley	0	0.78 $\pm$ 0.04 g		16.38 $\pm$ 2.34
	7	21.56 $\pm$ 1.76 f	2.97 $\pm$ 0.25 bc	11.48 $\pm$ 0.56
	10	31.98 $\pm$ 1.06 d	3.47 $\pm$ 0.35 b	11.41 $\pm$ 0.40
	13	49.06 $\pm$ 1.36 b	5.69 $\pm$ 0.45 a	10.85 $\pm$ 0.44
	16	56.08 $\pm$ 1.83 q	2.34 $\pm$ 0.61 d	11.15 $\pm$ 0.38

All means and SD are calculated from 6 samples collected in 2 blocks and 3 replicates per block

Different letters in a column indicate statistical difference among the sample means ($p < 0.05$)

Table 3 Correlation coefficients among Chl, Chl a, Chl b and Car in wheat and barley grasses

	Total Chl	Total Car	Cha a	Chl b
Total Chl	1.0000			
Total Car	0.9926	1.0000		
Cha a	0.9999	0.9932	1.0000	
Chl b	0.9996	0.9910	0.9992	1.0000

reported statistically significant correlations between Chl a, Chl b, total Chl and Car of ten maize varieties. The significant correlation applies to the given growth conditions and may not be valid when the level of irradiance and temperature during growth are altered (Haldimann 1999; Lichtenthaler 2007).

Comparison with some common vegetables

The Chl contents of micro-greens cultivated are slightly lower than Kale (820 ± 100 mg/100 g DM) and comparable to Spinach (780 ± 160 mg/100 g DM) (Gedi et al. 2017) but twice of chicory (175–370 mg/100 g DM) (Znidarcic et al. 2011) and 2–5 times of broccoli (135–280 mg/100 g DM) (Farnham and Kopsell 2009). The Car content of wheat and barley micro-greens are slightly lower than Kale (75.51–101.95 mg/100 g DM), chard (76.59–82.08 mg/100 g DM) and lettuce (69.69–78.3 mg/100 g DM) and comparable to carrot (45.05–73.68 mg/100 g DM), but higher than leek (29.33–40.78 mg/100 g DM) and 2–4 times of broccoli (13.7–25.4 mg/100 g DM) (Yoon et al. 2012). Though Chl and Car content of micro-greens in our study (winter and daylight) are lower than Kale and spinach, this can be overcome by doubling the content when cultivation in

summer and in sunlight (Kopsell et al. 2005; Skoczylas et al. 2018).

Conclusion

Chl a, Chl b, total Chl and Car in both micro-greens increased during study up to 16 days, with the maximum rate of accumulation between days 7–10 in wheat and between days 10–13 in barley. Pigments content after day 13 were not different on the variety and depended on the number of days of growth. The findings of this study suggests that, the pigments in cereal micro-greens do not reach their peak concentration within second week, but the rate of accumulation of these pigments afterwards is slow. The final Chl content of micro-greens at day 16 was slightly lower than Chl rich vegetables like Kale and comparable to spinach and the Car content was comparable to carrots. Cereal micro-greens can therefore be considered as Chl and Car rich health promoting food ingredients having a potential for nutraceutical and pharmaceutical use.

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References

- Battersby AR (1988) Biosynthesis of the pigments of life. *J Nat Prod* 51:629–642
- Beck WA, Redman R (1940) Seasonal variations in the production of plant pigments. *Plant Physiol* 15:81–94
- Benincasa P, Galieni A, Anna CM, Pace R, Guiducci M, Pisante M, Stagnari F (2015) Phenolic compounds in grains, sprouts and wheatgrass of hulled and non-hulled wheat species. *J Sci Food Agric* 95:1795–1803

- Chen K, Roca M (2018) In vitro bioavailability of chlorophyll pigments from edible seaweeds. *J Funct Foods* 41:25–33
- During A, Doraiswamy S, Harrison EH (2008) Xanthophylls are preferentially taken up compared with b-carotene by retinal cells via a SRBI-dependent mechanism. *J Lipid Res* 49:1715–1724
- Eldahshan OA, Singab ANB (2013) Carotenoids. *J Pharmacogn Phytochem* 2:225–234
- Farnham MW, Kopsell DA (2009) Importance of genotype on carotenoid and chlorophyll levels in broccoli heads. *HortScience* 44:1248–1253
- Filimon RV, Rotaru L, Filimon RM (2016) Quantitative investigation of leaf photosynthetic pigments during annual biological cycle of *Vitis vinifera* L. table grape cultivars. *S Afr J Enol Vitic* 37:1–14
- Gedi MA, Briars R, Yuseli F, Zainol N, Darwish R, Salter AM, Gray DA (2017) Component analysis of nutritionally rich chloroplasts: recovery from conventional and unconventional green plant species. *J Food Sci Technol* 54:2746–2757
- Haldimann P (1999) How do changes in temperature during growth affect leaf pigment composition and photosynthesis in *Zea mays* genotypes differing in sensitivity to low temperature? *J Exp Bot* 50:543–550
- Holm G (1954) Chlorophyll mutations in barley. *Acta Agric Scand* 4:457–471
- Januskaitiene I, Klepeckas M (2015) The effect of equal Cd and Cu exposure in peat substrate on growth and bioaccumulation of *Hordeum vulgare*. *Biologija* 61:83–93
- Kohler GO (1944) The effect of stage of growth on the chemistry of the grasses. *J Biol Chem* 152:215–223
- Kopsell DA, Kopsell DE, Curran-Celentano J (2005) Carotenoid and chlorophyll pigments in sweet basil grown in the field and greenhouse. *HortScience* 40:1230–1233
- Lefsrud M, Kopsell D, Wenzel A, Sheehan J (2007) Changes in kale (*Brassica oleracea* L. var. acephala) carotenoid and chlorophyll pigment concentrations during leaf ontogeny. *Sci Hortic* 112:136–141
- Lichtenthaler HK (2007) Biosynthesis, accumulation and emission of carotenoids, a-tocopherol, plastoquinone, and isoprene in leaves under high photosynthetic irradiance. *Photosynth Res* 92:163–179
- Lichtenthaler HK, Wellburn AR (1983) Determinations of total carotenoids and chlorophylls a and b of leaf extracts in different solvents. *Biochem Soc Trans* 11:591–592
- Meng FL, Xv YY, Hu JD, He D, Jiang JH (2017) Optimization of combined drying process by hot-air and microwave for barley seedling powder. *J Food Saf Qual* 8:1651–1658
- Ndukwe OK, Edeoga HO, Okwulehie IC, Omosun G (2016) Variability in the Chlorophyll and Carotene Composition of ten maize (*Zea mays*) varieties. *Eur J Phys Agric Sci* 4:1–6
- Niroula A, Khatri S, Khadka D, Timilsina R (2019) Total phenolic contents and antioxidant activity profile of selected cereal sprouts and grasses. *Int J Food Prop* 22:427–437
- Okpalanma FE, Ojimekwe PC (2018) Evaluation of effects of storage condition and processing on carotenoids, chlorophyll, vitamins and minerals in a water leaf (*Talinum triangulare*). *Asian Food Sci J* 2:41603
- Ozkose A, Arslan D, Acar A (2016) The comparison of the chemical composition, sensory, phenolic and antioxidant properties of juices from different wheatgrass and turfgrass species. *Not Bot Horti Agrobot Cluj-Napoca* 44:499–507
- Padalia S, Drabu S, Raheja I, Gupta A, Dhamija M (2010) Multitude potential of wheatgrass juice (Green Blood): an overview. *Chron Young Sci* 1:23–28
- Paznoch L, Kotíková Z, Miloslav Š, Lachman J, Orsák M, Eliášová M, Martinek P (2018) Free and esterified carotenoids in pigmented wheat, tritordeum and barley grains. *Food Chem* 240:670–678
- Rosevear MJ, Young AJ, Johnson GN (2001) Growth conditions are more important than species origin in determining leaf pigment content of British plant species. *Funct Ecol* 15:474–480
- Samanta T, Kotamreddy JNR, Ghosh BC, Mitra A (2017) Changes in targeted metabolites, enzyme activities and transcripts at different developmental stages of tea leaves: a study for understanding the biochemical basis of tea shoot plucking. *Acta Physiol Plant* 39:11
- Shah SH, Houborg R, McCabe MF (2017) Response of chlorophyll, carotenoid and SPAD-502 measurement to salinity and nutrient stress in wheat (*Triticum aestivum* L.). *Agronomy* 7:61
- Simova-stoilova L, Stoyanova Z, Demirevska-kepova K (2001) Ontogenic changes in leaf pigments, total soluble proteins and Rubisco in two barley varieties in relation to yield. *Bulgarian J Plant Physiol* 27:15–24
- Siriwatanametanon N (2017) Warfarin-chlorophyll products, herb-drug interactions. *Pharm Sci Asia* 44:173–189
- Skoczylas L, Korus A, Tabaszewska M, Gedos K, Szczepanska E (2018) Evaluation of the quality of fresh and frozen wheatgrass juices depending on the time of grass harvest. *J Food Process Preserv* 43:1–8
- Wakeham P (2013) The medicinal and pharmacological screening of wheatgrass juice (*Triticum aestivum* L.): an investigation into chlorophyll content and antimicrobial activity. *Plymouth Stud Sci* 6:20–30
- Wolf FT (1963) Effects of light and darkness on biosynthesis of carotenoid pigments in wheat seedlings. *Plant Physiol* 38:649–652
- Yang CM, Lee CN, Chou CH (2002) Effects of three allelopathic phenolics on chlorophyll accumulation of rice (*Oryza sativa*) seedlings: I. Inhibition of supply-orientation. *Bot Bull Academia Sinica* 43:299–324
- Yoon GA, Yeum KJ, Cho YS, Chen CYO, Tang G, Blumberg JB, Russell RM, Yoon S, Lee-Kim YC (2012) Carotenoids and total phenolic contents in plant foods commonly consumed in Korea. *Nutr Res Pract* 6:481–490
- Zaripheh S, Erdman JW (2002) Factors that influence the bioavailability of xanthophylls. In: Can lutein protect against chronic disease? pp S531–S534
- Znidarcic D, Ban D, Šircelj H (2011) Carotenoid and chlorophyll composition of commonly consumed leafy vegetables in Mediterranean countries. *Food Chem* 129:1164–1168

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