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Correlation of photosynthetic pigments content with indicators of seed quality in the seeds of carrot, celery, dill, parsley, and parsnip

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ABSTRACT: The content of photosynthetic pigments, especially chlorophylls, has a significant effect on the quality, viability, and storability of seeds. Determination of photosynthetic pigments together with the correlation with seed quality parameters, such as germination and radicle emergence, lead to the possibility of using the pigments content as a new indicator of seed quality. The photosynthetic pigments content was determined spectrophotometrically from extracts of commercial mature seeds of carrot, celery, dill, parsley, and parsnip. The content of chlorophyll *a*, chlorophyll *b*, β-carotene, and lutein varied among species of family Apiaceae and among varieties within species. Spectrophotometry was verified as easy, quick, and inexpensive method that can be used for the determination of photosynthetic pigments in mature seeds. The individual pigments content was compared to seed quality parameters such as standard germination, germination speed index (GSI), and radicle emergence (RE), which was carried out at 72, 96, 120, 144, and 168 h. Based on the correlation of photosynthetic pigments content with seed quality parameters (GSI and RE), chlorophyll *b* and lutein content were selected, and can be used as the new markers of seed quality.

Index terms: Apiaceae, carotenoids, chlorophyll, germination, radicle emergence.

RESUMO: O conteúdo de pigmentos fotossintéticos, especialmente clorofila, tem um efeito significativo na qualidade, viabilidade e capacidade de armazenamento das sementes. A determinação de pigmentos fotossintéticos, juntamente com a correlação com parâmetros de qualidade de sementes, como germinação e emergência da raiz primária, permite a utilização do teor de pigmentos como um novo indicador da qualidade das sementes. O teor de pigmentos fotossintéticos foi determinado espectrofotometricamente a partir de extratos de sementes comerciais maduras de cenoura, aipo, endro, salsa e nabo. O conteúdo de clorofila a, clorofila b, β-caroteno e luteína diferiu entre as espécies da família Apiaceae e também entre as variedades dentro das espécies. A espectrofotometria provou ser um método fácil, rápido e barato para a determinação de pigmentos em sementes maduras. O conteúdo de pigmentos individuais foi comparado com parâmetros de qualidade de sementes, como germinação, índice de velocidade de germinação (IVG) e emergência da raiz primária (ER), que foi realizado às 72, 96, 120, 144 e 168 h. Com base na correlação do conteúdo de pigmentos com a qualidade das sementes (IVG e ER), foram selecionados teores de clorofila *b* e luteína que podem ser usados como novos marcadores de qualidade de sementes.

Termos de indexação: Apiaceae, carotenoides, clorofila, germinação, emergência de radícula.

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INTRODUCTION

It is generally known that photosynthetic pigments, such as chlorophylls and carotenoids, are present in green parts of plants such as leaves and their key role is to participate in photosynthesis. However, chlorophylls and carotenoids can also be found in developing and mature seeds (Smolikova and Medvedev, 2016). Changes in the chlorophyll content occur during embryogenesis of various species, but during the late stage of seed maturation, chlorophyll is degraded as described for *Arabidopsis thaliana* (Allorent et al., 2015), *Pisum sativum* (Smolikova et al., 2018), and others. Nevertheless, chlorophyll is not completely degraded and the so-called residual chlorophyll is found in the mature seeds (Smolikova et al., 2017). The presence of chlorophyll together with carotenoids have been studied in a number of species and was found that the chlorophyll content is related to the seed quality, in particular by decreasing vigour, longevity of the seed, or the quality of produced oils.

The determination of the chlorophyll content in the mature seeds of diverse crop species could be used as a marker for seed quality (Sano et al., 2016). Jalink et al. (1998) have already suggested chlorophyll fluorescence of the testa of *Brassica oleracea* seeds as an indicator of seed maturity and seed quality, and this technique has been applied in numerous species such as *Oryza sativa* (Hay et al., 2015) and *Capsicum annuum* (Kenanoglu et al., 2016). Other methods for assessment of the photosynthetic pigments in the seed tissues are spectrophotometric analysis and high-performance liquid chromatography (HPLC), which was performed in seeds of *Glycine max* (Teixeira et al., 2016) or wild species of Fabaceae (Fernández-Marín et al., 2017). The spectrophotometric measurement of chlorophylls and carotenoids in mature seeds has been successfully used in other studies, that was performed with various solvents such as acetone (Allorent et al., 2015), dimethylformamide (Zinsmeister et al., 2016), methanol (Smolikova et. al., 2018), or petroleum ether and tetrahydrofuran (Bulda et al., 2008; Smolikova et al., 2011; Grulichova et al., 2018).

In seed production, the seed quality is commonly evaluated by the germination and vigour tests. Nevertheless, the large disadvantage of the germination test is the possible difference between laboratory germination and field emergence. For this reason, there are numbers of vigour tests, for example accelerated aging, electrical conductivity, controlled deterioration and radicle emergence. The radicle emergence (RE) test is simple method, which is indicative of the percentage of normal seedlings that is closely related to the germination speed index (GSI). The RE has been applied to a wide range of species such as *Allium ampeloprasum* (Ermis et al., 2015), *Cicer arietinum* (Akbarpour et al., 2019), or *Lepidium sativum* (Demir et al., 2019) and is an ISTA-validated as a vigour test for *Zea mays* (Matthews et al., 2011), *Brassica napus* (Powell et al., 2014), *Raphanus sativus* (Powell and Mavi, 2016), and *Triticum aestivum* (Khajeh-Hosseini et al., 2019).

In this study, we focused on the determination of the photosynthetic pigments content, especially chlorophyll *a*, chlorophyll *b*, β-carotene, and lutein, in mature seeds of commercially available species of the family Apiaceae using a simple spectrophotometric method after one year of storage. Furthermore, we focused on the evaluation of RE together with the standard laboratory germination test for the more comprehensive evaluation of seed quality and also for possible use as the vigour test. However, the main aim was to assess the correlation of the photosynthetic pigments content in the mature seeds with indicators of seed quality such as RE and the standard laboratory germination.

MATERIALS AND METHODS

The seeds of five species, each with three or four varieties of the family Apiaceae were provided by the seed companies SEMO a.s. (Smrzice, CZ) and MORAVOSEED CZ, (Mikulov, CZ). The seed companies provided the seed lots which were harvested in 2017, not chemically treated, disease-free, and commercially available. These were varieties of carrot (*Daucus carota* L.): Jitka, Jolana, Marion, and Olympus; celery (*Apium graveolens* L.): Albin, Jemny, Malachit, and Nuget; dill (*Anethum graveolens* L.): Hanak, Monarch, Moravan, and Oliver; parsley (*Petroselinum crispum* L.): Atika, Olomoucka dlouha, and Orbis; and parsnip (*Pastinaca sativa* L.): Albion, Bielas, and Dlouhy bily. The commercially available seed lots were stored in the cold (5 °C), at dry and dark place, unselected, and untreated that means under standard conditions used in seed companies.

Determination of pigments in the seeds

The seed samples (500 mg) were ground in a laboratory mill (Analysette 3 SPARTAN, Fritsch) for six minutes. The homogenate was mixed with 2 mL PE and THF in ration 1:1. Subsequently, the 3 mL PE was added, and the mixture was filtered through a syringe filter with nylon (polyamide, 0.45 µm pore size). The sample was then rinsed twice with 3 mL PE and THF (4:1). Chlorophyll *a,* chlorophyll *b*, β-carotene, and lutein were measured at 645, 655, 480, and 495 nm, respectively, using a spectrophotometer (Spectronic 20 Genesys, Thermo Scientific). The pigment content was calculated in mg/L from equations presented by Bulda et al. (2008):

$$C_a = 19.00\ A_{655} - 7.61\ A_{645},\ C_b = 21.45\ A_{645} - 5.92\ A_{655},$$

$$C_{\beta\text{-car}} = 17.16\ A_{495} - 3.96\ A_{480},\ C_{lut} = 11.51\ A_{480} - 20.61\ A_{495}$$

The total content of chlorophylls and carotenoids were calculated as the sum of chlorophyll *a* and chlorophyll *b* and β-carotene and lutein, respectively. The pigment content was then converted to $\mu g.g^{-1}$ dry wt. Each of the seed sample measurement was performed in triplicate.

Germination test

The germination test was carried out as a standard laboratory germination test according to the CISTA methodology (2014) for every plant species. Four replications of 50 seeds each were place on moistened filter paper (Whatman, Grade 1) in Petri dishes (⌀ 14 cm). The germination conditions were 16/8 hours light/dark cycle at alternating 20/30 °C in a growth chamber. During the germination test, the germination speed index (GSI) was evaluated after 6 days for parsnip, 7 days for carrot and dill, 10 days for celery and parsley. The total germination (G) of normal developed seedlings, abnormal seedlings and dead or non-germinated seeds were assessed after 14 days for carrot, 21 days for celery and dill, 28 days for parsley and parsnip.

Radicle emergence test

The radicle emergence test was performed with the standard laboratory germination test using one test for every variety. Radicle emergence, min. 2 mm in length, was assessed after 24, 48, 72, 96, 120, 144, and 168 h. Culture conditions were 16/8 hours light/dark cycle at alternating 20/30 °C. Test was performed in four replications of 50 seeds each.

Statistical analysis was performed using Microsoft Office Excel 2019 and STATISTICA 12 (StatSoft CZ, Inc.) - ANOVA ($\alpha = 0.05$) and Pearson´s correlation ($\alpha = 0.05$, 0.01 or 0.001) between photosynthetic pigments, radicle emergence and germination, germination speed index, and photosynthetic pigments and radicle emergence, germination, germination speed index.

RESULTS AND DISCUSSION

The chlorophylls and carotenoids content varied among species of family and among varieties within species (Table 1). The highest content of chlorophyll *a*, *b,* and lutein was in parsley of variety Ol. Dlouha, celery of variety Jemny, carrot, except for variety Olympus, and parsnip, except for Albion, and the highest content of β-carotene was in parsley of variety Ol. Dlouha and parsnip, except for Albion. On the contrary, the lowest chlorophyll *a*, *b* and lutein was in celery of variety Nuget and parsley, except for Ol. Dlouha, and the lowest β-carotene content in celery of variety Nuget and Albin. The carotenoids content compared to chlorophylls were generally much lower, except for celery of variety Nuget, and the content of chlorophyll *a* was higher than chlorophyll *b*, which is in accordance with studies of Bulda et al. (2008); Smolikova et al. (2011); and Grulichova et al. (2018). These trends in chlorophyll content have been confirmed by Smolikova et al. (2011) in physiologically mature seeds of many other species such as *Brassica napus, Daucus carota, Galega orientalis*, *Glycine max, Lupinus angustifolius, Vicia sativa*, and *Zea mays*.

Table 1. Chlorophylls and carotenoids content in seeds of varieties of five Apiaceae species.

Species	Variety	Chlorophylls (ug.g^{-1} dry wt)			Carotenoids (ug.g^{-1} dry wt)		
		Chl *a*	Chl *b*	Chls	β-carotene	Lutein	Car
Carrot	Jitka	22.60 a	20.81 a	43.41 a	7.12 a	9.18 a	16.30 a
	Jolana	19.29 b	17.56 b	36.85 b	5.25 b	8.95 a	14.20 b
	Marion	17.38 b	15.46 b	32.84 b	3.90 c	7.06 b	10.96 c
	Olympus	7.24 c	6.26 c	13.50 c	3.22 c	3.51 c	6.73 d
Celery	Albin	7.44 c	5.05 c	12.49 c	2.05 b,c	2.62 b	4.67 c
	Jemny	22.48 a	14.10 a	36.58 a	5.24 a	5.04 a	10.28 a
	Malachit	13.39 b	7.65 b	21.04 b	3.01 b	3.13 b	6.14 b
	Nuget	0.38 d	0.13 d	0.51 d	1.27 c	0.04 c	1.31 d
Dill	Hanak	11.19 a	8.47 a	19.66 a	4.32 a	5.39 a	9.71 a
	Monarch	8.81 b	7.56 a	16.37 a	3.32 a	3.79 a,b	7.11 b
	Moravan	6.48 c	3.95 b	10.43 b	4.19 a	2.43 b	6.62 b
	Oliver	9.21 b	7.68 a	16.89 a	3.21 a	3.34 b	6.55 b
Parsley	Atika	3.21 b	2.68 b	5.89 b	3.83 b	0.00 b	3.83 b
	Ol.dlouha	50.41 a	34.15 a	84.56 a	18.06 a	13.24 a	31.30 a
	Orbis	3.51 b	2.46 b	5.97 b	5.07 b	0.00 b	5.07 b
Parsnip	Albion	6.20 c	5.06 c	11.26 c	2.74 b	1.96 b	4.70 b
	Bielas	17.82 b	12.63 b	30.45 b	7.25 a	6.14 a	13.39 a
	Dlouhy bily	21.34 a	15.73 a	37.07 a	6.85 a	7.39 a	14.24 a

Chlorophyll a (Chl a), chlorophyll b (Chl b), chlorophylls (Chls), carotenoids (Car) and Olomoucka dlouha (Ol. dlouha). Means of three replications and different letters represent statistical significance differences ($p<0.05$) between varieties within species.

The statistically significant correlations were found between the pigments content in all species, except for β-carotene content in dill (Table 2). Although the correlation coefficients (r) were high, thus the representatives of chlorophylls and carotenoids were selected, namely chlorophyll *a* (optionally chlorophyll *b*) and lutein. Chlorophyll *b* was chosen based on the higher value of coefficient of determination (r^2) instead of chlorophyll *a* (Figure 1), and together with lutein content could also be used as the markers of seed quality.

The RE was counted at 72, 96, 120, 144, and 168 h. The counts at 24 and 48 h were excluded because of its zero values, except for celery, parsley, and parsnip species, where RE at 72 h was still zero (Table 3). In addition, RE was omitted at 168 h for species of carrot, dill, and parsnip, because it was also the time that the seedlings were counted to determine germination speed index. The RE varied among species of family and among varieties within every species at all time intervals, except for carrot and dill varieties at 144 h. The largest differences of RE were among carrot varieties at 72 h, celery varieties at 96 and 120 h, dill varieties at 72 and 96 h, and parsnip varieties at 144 h. Variety differences were observed also in seven wheat varieties at evaluated RE every 6 up to 72 h (Guan et al., 2018), and in four aubergine cultivars and their 23 seed lots evaluated RE at 96, 104, 112, 120, 128, and 136 h (Ozden et al., 2018).

The correlation of germination rate and germination speed index with RE were observed in carrot, celery, dill, and parsley; germination speed index with RE were observed in dill, parsley, and parsnip; germination with RE were observed in celery (Table 4). The REs were selected in order to be correlated with germination rates and the germination speed index for each species, except for parsnip, which correlated only with germination speed index at 96 h, namely RE at 96 h in carrot and parsley, 120 h in dill, and 144 h in celery (Figure 2). The correlation of RE with germination has been found in other studies in species such as oilseed rape lots after 48 h at 20°C (Matthews et al., 2018) or in aubergine after 104 h, where correlation coefficients were higher at fluctuating 20/30 °C than constant 25 °C (Ozden et al., 2018).

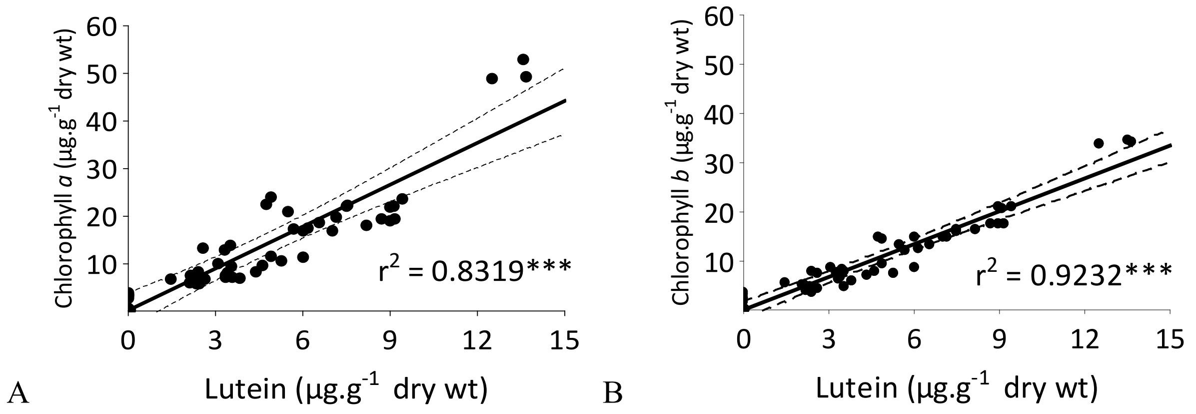
Table 2. Correlation coefficient (r) of photosynthetic pigments content of five Apiaceae species.

Species	Photosyntethic pigment	Photosynthetic pigment					
		Chlorophyll *a*	Chlorophyll *b*	Chlorophylls	β-carotene	Lutein	Carotenoids
Carrot	Chlorophyll *a*	-					
	Chlorophyll *b*	0.9966***	-				
	Chlorophylls	0.9992***	0.9991***	-			
	β-carotene	0.8305***	0.8406***	0.8361***	-		
	Lutein	0.9655***	0.9679***	0.9674***	0.7679**	-	
	Carotenoids	0.9671***	0.9729***	0.9707***	0.9124***	0.9628***	-
Celery	Chlorophyll *a*	-					
	Chlorophyll *b*	0.9946***	-				
	Chlorophylls	0.9992***	0.9979***	-			
	β-carotene	0.9593***	0.9634***	0.9621***	-		
	Lutein	0.9389***	0.9458***	0.9427***	0.8313***	-	
	Carotenoids	0.9905***	0.9963***	0.9940***	0.9486***	0.9645***	-
Dill	Chlorophyll *a*	-					
	Chlorophyll *b*	0.9290***	-				
	Chlorophylls	0.9814***	0.9828***	-			
	β-carotene	0.1610	0.0428	0.1032	-		
	Lutein	0.8255***	0.6642*	0.7564**	-0.1333	-	
	Carotenoids	0.8188**	0.6049*	0.7227**	0.5061	0.7873**	-
Parsley	Chlorophyll *a*	-					
	Chlorophyll *b*	0.9988***	-				
	Chlorophylls	0.9998***	0.9996***	-			
	β-carotene	0.9944***	0.9915***	0.9935***	-		
	Lutein	0.9988***	0.9987***	0.9990***	0.9898***	-	
	Carotenoids	0.9991***	0.9976***	0.9988***	0.9975***	0.9974***	-
Parsnip	Chlorophyll *a*	-					
	Chlorophyll *b*	0.9978***	-				
	Chlorophylls	0.9996***	0.9992***	-			
	β-carotene	0.9359***	0.9155***	0.9280***	-		
	Lutein	0.9886***	0.9876***	0.9887***	0.9019***	-	
	Carotenoids	0.9881***	0.9777***	0.9844***	0.9725***	0.9777***	-

Significance *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

In addition, the significant correlation of RE with germination speed index was also observed in wheat varieties after 48 h and 72 h at 20 °C and 13 °C, respectively (Guan et al, 2018). In this study, the results of radicle emergence test showed the possibility of use as a vigour test for carrot, celery, dill, parsnip, and parsley, as well as for a number of species in the above-mentioned studies.

Increased content of chlorophylls and carotenoids caused lower RE in carrot at 72 and 96 h, parsley at 120, 144, and 168 h, and parsnip at 96, 120, and 144 h, but also higher RE in dill at 72 h and 96 h (increased content of chlorophylls and lutein), and in celery at 96 h (increased content of chlorophyll *b* and lutein) (Table 5). Germination speed index decreased with higher chlorophylls and carotenoid content in parsnip, in parsley (increased content of β-carotene and carotenoids), and in carrot (increased content of lutein), but also increased GSI in dill with higher content of chlorophyll *a*, *b*, and chlorophylls. No effect of chlorophylls and carotenoids content and germination has been demonstrated, except for content of lutein in carrot. Similarly, the correlation of pigments content in seeds with indicators of seed



Confidence interval (dashed lines) and coefficient of determination (r^2) with significance *** $p < 0.001$.

Figure 1. Relationship between chlorophyll *a* and lutein content (A) and chlorophyll *b* and lutein content (B) of family Apiaceae.

Table 3. Radicle emergence at 72, 96, 120, 144, and 168 h, germination, and germination speed index in seeds of varieties of five Apiaceae species.

Species	Variety	Radicle emergence (%)					GSI (%)	G (%)
		72 h	96 h	120 h	144 h	168 h		
Carrot	Jitka	48 b	73 b	83 b	86 a	n.a.	73 b	87 a
	Jolana	45 b	71 b	76 c	85 a	n.a.	60 b	72 b
	Marion	68 a	85 a	88 a	88 a	n.a.	84 a	88 a
	Olympus	67 a	85 a	88 a	89 a	n.a.	83 a	92 a
Celery	Albin	0	49 a	87 a	95 a	97 a	91 a,b	97 a
	Jemny	0	42 a	71 b	83 b,c	85 b	84 b	92 b
	Malachit	0	24 b	79 a,b	90 a,b	95 a	93 a	99 a
	Nuget	0	9 c	48 c	74 c	81 b	85 a,b	91 b
Dill	Hanak	83 a	84 a	84 a	84 a	n.a.	80 a	83 a
	Monarch	71 a	76 a,b	82 a,b	82 a	n.a.	81 a	83 a
	Moravan	38 b	61 c	75 b	79 a	n.a.	67 b	80 a
	Oliver	70 a	75 b	75 b	81 a	n.a.	77 a	78 a
Parsley	Atika	0	13 a	61 a	85 a	93 a	87 a	92 a
	Ol.dlouha	0	1 b	13 c	25 c	44 c	59 b	83 a,b
	Orbis	0	3 b	51 b	65 b,c	75 b	66 b	75 b
Parsnip	Albion	0	5 a	19 a	30 a	n.a.	49 a	91 a
	Bielas	0	1 b	6 b	13 b	n.a.	19 b	89 a
	Dlouhy bily	0	0 b	2 b	7 b,c	n.a.	10 c	89 a

Germination speed index (GSI), standard laboratory germination (G), hours (h), not assessed (n.a.) and Olomoucka dlouha (Ol. dlouha). Means of three replications and different letters represent statistical significance differences ($p<0.05$) between varieties within species.

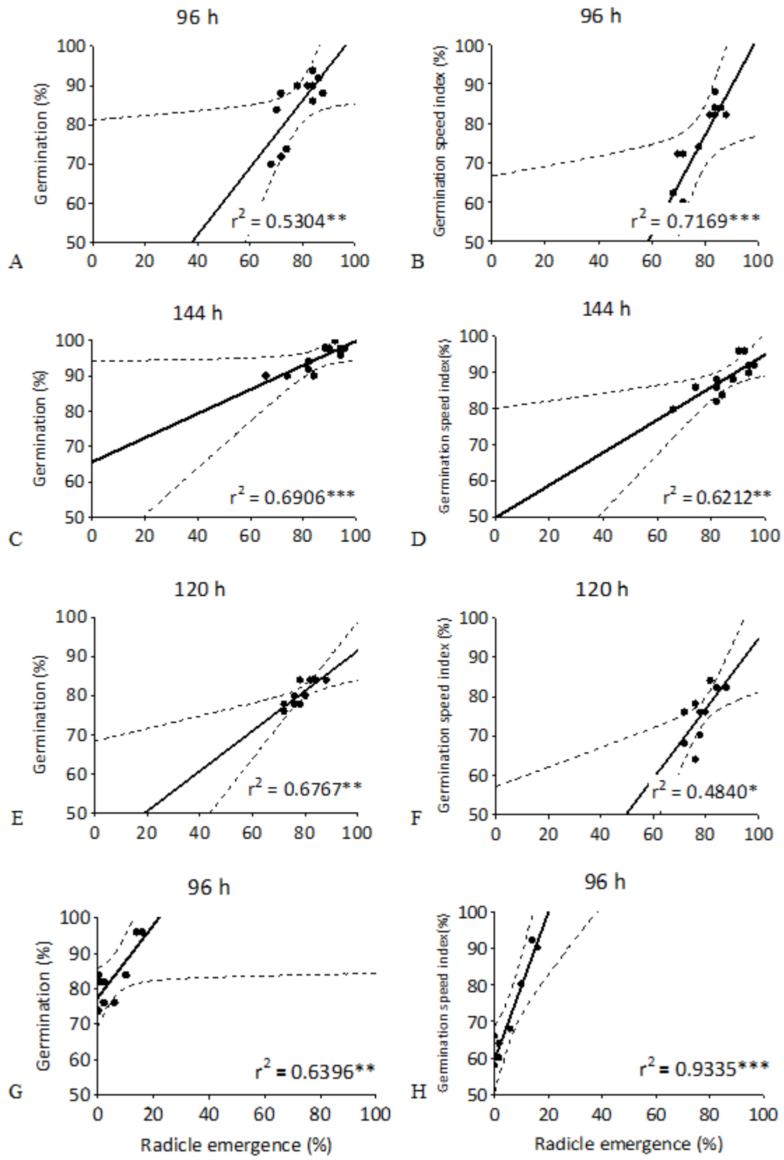
quality such as standard germination and seedling emergence, were performed by Grulichova et al. (2018). They observed negative correlation of pigments with germination speed index and seedling emergence only in parsley and parsnip varieties (Grulichova et al., 2018).

Based on the correlation coefficients of radicle emergence with germination and germination speed index (Table 4) and photosynthetic pigment content with radicle emergence (Table 5), were selected RE at 96 h in carrot, celery, dill, and parsnip, RE at 168 h in parsley, and chlorophyll *b* and lutein (Figure 3). Chlorophyll *b* and lutein contents

Table 4. Correlation coefficient (r) of radicle emergence at 72, 96, 120, 144, and 168 h with germination and germination speed index of five Apiaceae species.

RE	Carrot		Celery		Dill		Parsley		Parsnip	
(h)	G	GSI	G	GSI	G	GSI	G	GSI	G	GSI
72	0.6913*	0.8145**	n.a.	n.a.	0.3720	0.8967***	n.a.	n.a.	n.a.	n.a.
96	0.7283**	0.8467***	0.2876	0.1882	0.4953	0.8610***	0.7998**	0.9662***	0.2359	0.9276***
120	0.8967***	0.9197***	0.7394**	0.5574	0.8226**	0.6957*	0.2571	0.7883*	0.3930	0.9559***
144	0.4302	0.4108	0.8310***	0.7882**	0.7733**	0.7537**	0.3393	0.8460**	0.2896	0.9670***
168	n.a.	n.a.	0.9237***	0.8089**	n.a.	n.a.	0.3937	0.8704**	n.a.	n.a.
GSI	0.8713***		0.8587***		0.5786*		0.7768*		0.3324	

Germination speed index (GSI), standard laboratory germination (G), hours (h) and not assessed (n.a.). Significance *p < 0.05, **p < 0.01, ***p < 0.001.



Confidence interval (dashed lines) and coefficient of determination (r^2) with significance * p < 0.05, ** p < 0.01, *** p < 0.001.

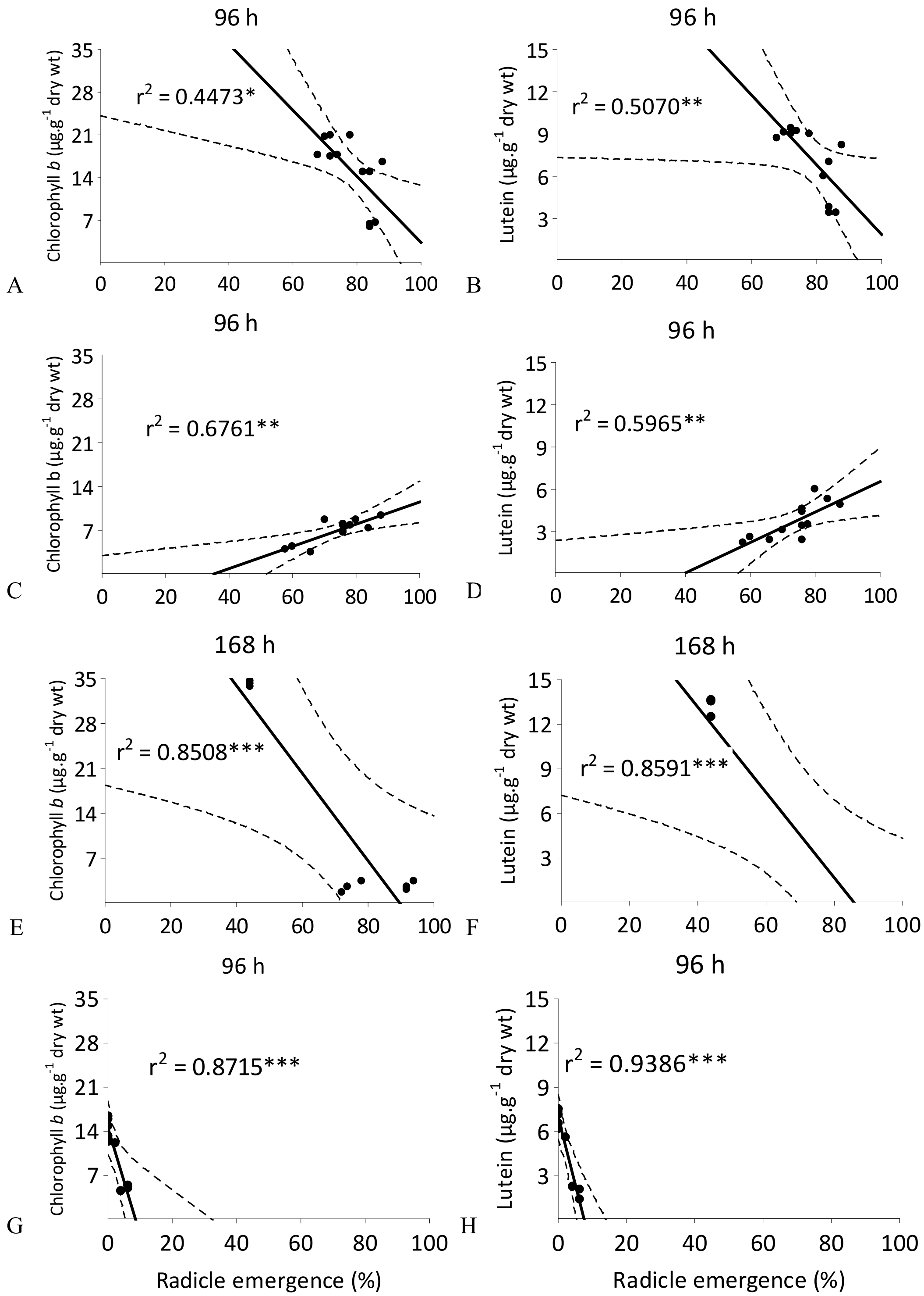
Figure 2. Relationship between radicle emergence at 96, 120, and 144 hours (h) and germination or germination speed index in carrot (A, B), celery (C, D), dill (E, F) and parsley (G, H).

Table 5. Correlation coefficient (r) of photosynthetic pigment content with radicle emergence at 72, 96, 120, 144, and 168 h, germination speed index, and germination of five Apiaceae species.

Species	Variety	Radicle emergence					GSI (%)	G (%)
		72 h	96 h	120 h	144 h	168 h		
Carrot	Chlorophyll *a*	- 0.6355*	- 0.6685*	- 0.5432	- 0.3610	n.a.	- 0.5550	- 0.4658
	Chlorophyll *b*	- 0.6670*	- 0.6688*	- 0.5443	- 0.3393	n.a.	- 0.5654	- 0.4674
	Chlorophylls	- 0.6512*	- 0.6692*	- 0.5441	- 0.3507	n.a.	- 0.5605	- 0.4669
	β-carotene	- 0.7229**	- 0.7889**	- 0.5085	- 0.2886	n.a.	- 0.5673	- 0.2853
	Lutein	- 0.7055*	- 0.7120**	- 0.6883*	- 0.4486	n.a.	- 0.6889*	- 0.6115*
	Carotenoids	- 0.7229**	- 0.7889**	- 0.5085	- 0.2886	n.a.	- 0.5673	- 0.2853
Celery	Chlorophyll *a*	n.a.	0.5432	0.4446	0.2374	0.	- 0.0524	0.0501
	Chlorophyll *b*	n.a.	0.5926*	0.4546	0.2595	0.1579	- 0.0672	0.0222
	Chlorophylls	n.a.	0.5628	0.4489	0.2461	0.1534	- 0.0582	0.0393
	β-carotene	n.a.	0.4841	0.2675	0.0675	- 0.0235	- 0.2263	- 0.1554
	Lutein	n.a.	0.6563*	0.6141*	0.4206	0.2920	0.0832	0.1873
	Carotenoids	n.a.	0.6036*	0.4766	0.2713	0.1548	- 0.0605	0.0326
Dill	Chlorophyll *a*	0.8476***	0.8250***	0.5390	0.5055	n.a.	0.6805*	0.1379
	Chlorophyll *b*	0.8783***	0.8223**	0.5015	0.5094	n.a.	0.8005**	0.1244
	Chlorophylls	0.8785***	0.8380***	0.5289	0.5161	n.a.	0.7550**	0.1329
	β-carotene	- 0.1515	- 0.0872	- 0.1652	- 0.0694	n.a.	- 0.0802	- 0.1143
	Lutein	0.7612**	0.7723**	0.6037*	0.4943	n.a.	0.5230	0.2857
	Carotenoids	0.5681	0.6173*	0.6272*	0.4721	n.a.	0.4046	0.3184
Parsley	Chlorophyll *a*	n.a.	- 0.5887	- 0.9745***	- 0.9476***	- 0.9284***	- 0.6634	- 0.0646
	Chlorophyll *b*	n.a.	- 0.5710	- 0.9694***	- 0.9432***	- 0.9224***	- 0.6512	- 0.0458
	Chlorophylls	n.a.	- 0.5818	- 0.9728***	- 0.9461***	- 0.9263***	- 0.6587	- 0.0571
	β-carotene	n.a.	- 0.6425	- 0.9786***	- 0.9658***	- 0.9458***	- 0.7161*	- 0.1352
	Lutein	n.a.	- 0.5781	- 0.9728***	- 0.9447***	- 0.9269***	- 0.6577	- 0.0604
	Carotenoids	n.a.	- 0.6124	- 0.9783***	- 0.9578***	- 0.9389***	- 0.6891*	- 0.0988
Parsnip	Chlorophyll *a*	n.a.	- 0.9398***	- 0.9484***	- 0.9699***	n.a.	- 0.9904***	- 0.2684
	Chlorophyll *b*	n.a.	- 0.9335***	- 0.9500***	- 0.9708***	n.a.	- 0.9903***	- 0.2764
	Chlorophylls	n.a.	- 0.9377***	- 0.9496***	- 0.9708***	n.a.	- 0.9909***	- 0.2717
	β-carotene	n.a.	- 0.8775**	- 0.8437**	- 0.8844**	n.a.	- 0.9275***	- 0.3161
	Lutein	n.a.	- 0.9688***	- 0.9638***	- 0.9770***	n.a.	- 0.9834***	- 0.2778
	Carotenoids	n.a.	- 0.9489***	- 0.9298***	- 0.9568***	n.a.	- 0.9812***	- 0.3033

Germination speed index (GSI), standard laboratory germination (G), hours (h) and not assessed (n.a.). Significance *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

were selected as representatives of photosynthetic pigments, which could possibly be used as the markers of seed quality. Relatively recent study by Teixeira et al. (2020) compared soybean seed lots with 0-18% of green seeds for various indicators of seed quality such as germination, first germination count, electrical conductivity, accelerated aging, or field emergence. This determined that the presence of chlorophyll caused the quality of seeds to decrease. Similarly, we observed this trend in our study and increasing chlorophyll*s* decreased RE and germination speed index in carrot, parsley and parsnip, but in the case of dill and celery there was an increased RE and GSI.



Confidence interval (dashed lines) and coefficient of determination (r^2) with significance * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Figure 3. Relationship between radicle emergence at 96 and 168 hours (h) and chlorophyll *b* or lutein contents in carrot (A, B), dill (C, D), parsley (E, F) and parsnip (G, H) species.

CONCLUSIONS

The chlorophylls and carotenoids content in mature seeds of five species of the family Apiaceae can be determined by using a simple spectrophotometric method with the levels of individual pigments differing among species within family and among varieties within species. The pigments content can be correlated to the seed quality parameters of standard germination, germination speed index, and radicle emergence, which seems to be suitable as indicators of seed quality for seed industry.

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