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Use of Leaf Physiological Traits as Adaptability Indicators for Screening Chili-Pepper Genotypes During the Multi-Site Testing

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Chlorophyll and carotenoid present in chloroplasts of higher plants can be used to predict crop adaptability. This study aimed to determine relationships between leaf physiological traits (chlorophyll *a*, *b*, ratio *a/b*, total chlorophyll, carotenoid, ratio of total chlorophyll to carotenoid and leaf relative water content) with yields of five chili pepper genotypes, and to determine which LPTs can predict chili pepper adaptation to Ultisol, Organosol and Regosol. Three separated experiments were conducted in Bengkulu, Indonesia, from January to June 2014, arranged in randomized complete block design with three replicates. Eight chili pepper genotypes, five promising genotypes (H13, H23, H43, H53 and H73), P3 (its ancestor) and two commercial hybrids of IPBCH3 and Tilala. Results indicated that chlorophyll *a* and total chlorophyll can positively predict fruit-length in Ultisol. However, leaf relative water content can negatively predict fruit-diameter and fruit-weight. In Organosol, chlorophyll *a/b* and leaf relative water content positively can predict fruit-weight per plant and fruit-weight, respectively, but total chlorophyll can negatively predict fruit-length and fruit-diameter. Carotenoid can negatively predict fruit-weight. In Regosol, there were no leaf physiological traits can predict fruit-length, fruit-diameter, fruit-weight, and fruit-weight per plant. Chili pepper adaptability to three different types of soil indicated that H53 was the most adaptive genotype in Ultisol, followed by H13. In Organosol, H43 was the most adaptive genotype, followed by H13. In Regosol, H53 was the most adaptive genotype, followed by H13. Overall, H13 was a wide range genotype adaptive to Ultisol, Organosol, and Regosol.

Keywords: chili pepper, chlorophyll, carotenoid, leaf water content, adaptability indicators

Introduction

A multi-site testing, aims to determine genotypic performance and adaptability over representative environments of production areas, is a necessary phase in breeding programs, before releasing a new cultivar to the markets. It is commonly practiced that performance and adaptability of promising genotypes are measured by means of crop growths and yields, including in chili-peppers (Syukur *et al.,* 2011; Ganefianti *et al*., 2012; Fitriani *et al*., 2013; Herison *et al*., 2014). Such parameters might include

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the characters of leaves, stems, flowers, fruits, seeds, and other physical attributes, which are all very labor intensive and time-consuming. Measurements of leaf physiological traits might be considered as a less popular technique to determine crop responses to particular growing environments. However, these approaches are vast and reliable since leaf physiological properties are directed to responsible for photosynthesis processes.

Both chlorophyll and carotenoid are the major pigments play significant roles in plant photosynthesis (Hendry and Price, 1993). According to Lichtentaler and Calvin (1964), carotenoid levels are directly proportional to the amount of chlorophyll in photosynthesis tissues. Furthermore, Hendry and Price (1993), Sairam and Saxena (2000), Simova-Stoilova *et al*. (2001), Roca and Minguez-Mosquera (2003), Gandul-Rojas *et al*. (2004), Sharifi *et al*. (2012) and Elshafei *et al*. (2013) concluded that the use of chlorophyll *a*, chlorophyll *b*, total chlorophyll, the ratio between chlorophyll *a* to chlorophyll *b*, and carotenoid content as well as ratio between chlorophyll and carotenoid could be used to study crop responses to environmental stresses and thylakoid membrane stability. Both chlorophylls and carotenoid serve as an antioxidant in plant cell to prevent the damage of lipid compositions in cell walls due to oxidative stress. According to Hendry and Price (1993), cell membrane stability has been widely used to express stress tolerance in plants in which higher membrane stability is correlated to stress tolerance. Furthermore, ratio of chlorophyll to carotenoid might be used as a potential indicator of oxidative damages.

Another stress indicator of leaf physiological traits as responses to environmental disturbances is leaf relative water content (Lobato *et al*., 2009; Garg and Singla, 2009). Leaf water status is intimately related to several leaf physiological variables, such as leaf turgor, growth, stomatal conductance, transpiration, photosynthesis and respiration (Kramer and Boyer, 1995). Measurements of water content that are generally expressed on a tissue fresh or dry mass basis have been mostly replaced by measurements based on the maximum amount of water a tissue can hold which is referred to as relative water content (Boyer, 1968). It has been reported that environmental stresses reduced leaf relative water content, *e.g.*, due to flooding (Min and Bartholomew, 2005), drought stress (Rahimi *et al*. 2010; Ananthi *et al*., 2013), and nutrient deficiency (Sun et al., 2011; Rezaiekinji and Rahdari, 2012).

Ganefianti *et al.* (2011) has successfully screened five promising chili-pepper genotypes (from 49 genotypes) that are potentially grown well in coastal areas where Ultisol, Organosol and Regosol mainly dominated its agricultural lands. The extension of chili-pepper production in lower altitude is expected to compensate the declining high-land production. Indirect method can be reliably used to determine whether a particular genotype is superior or not to any particular environment by monitoring and measuring all phenomena and processes related to crop productivity (Aranaya *et al*., 2003; Raynolds *et al*., 2000; Kof *et al*., 2004). There have been limited publications to correlate yield components and leaf physiological traits (LPTs), especially as a tool in breeding program to identify chili-pepper responses to any particular environments for multi-site testing. This research was conducted to study the relationships between LPTs (chlorophyll *a*, chlorophyll *b*, ratio of chlorophyll *a* to chlorophyll *b*, and total chlorophyll, carotenoid, ratio of total chlorophyll to carotenoid, leaf relative water content) and yield components of seven promising chili-pepper genotypes as well as to determine which one of LPTs can be used to predict chili-pepper adaptation to Ultisol, Organosol and Regosol environments.

Materials and methods

Three separated experiments were conducted on three different soil types, *i.e.* Ultisol, Organosol, and Regosol in low land of Bengkulu, Indonesia (15 meters above sea level) from January to June 2014. All experimental sets were arranged in randomized complete block design with three replicates. Seeds of promising cultivars were produced by reciprocal and self-progenies through a full diallel crossing in screen house of Crop Production Department, University of Bengkulu. There were eight chili pepper genotypes used in these experiments, *i.e.* five promising genotypes (H13, H23, H43, H53 and H73), P3 (one of their ancestor) and two commercial hybrids of IPBCH3 and Tilala that adapted to lowland soils.

The seedlings of each genotype (4-week-old) were transplanted into the field at a spacing of 0.6 m x 0.6 m on 3.6 m x 2.6 m soil bed (24 plants per plot). A week before transplanting, each planting hole was fertilized with 1 kg cow manure and 5 g NPK (16:16:16). Upon transplanting, each planting hole was applied with 8 pieces of carbofuran. Any buds appeared under dichotomous branches were manually pinched. The experimental plots were manually irrigated if two consecutive days there were no precipitation. At the same time of weeding (manually controlled), soil around the main stem was raised to prevent up-rooting. At four weeks after transplanting, each plant was fertilized with 5 g NPK (16:16:16). The plants were also staked with bamboo stick to prevent any physical disturbances.

Measurements of chlorophylls (chlorophyll *a*, chlorophyll *b*, ratio of chlorophyll *a* to chlorophyll *b*, and total chlorophyll), carotenoid, ratio of total chlorophyll to carotenoid as well as leaf relative water content were conducted by taken youngest most-expanded leaves, generally the third leaf from the plant shoots of sample plants. Chlorophyll from fresh tissue (0.5 g) was extracted using 80% acetone (Yoshida *et al*., 1976) . Absorbances of this extract were determined at 470 nm (A_{470}), 646 nm (A_{646}) and 663 nm (A_{663}) using UV/Visible Spectrophotometer. Calculations of concentration (μmol/L) of chlorophyll *a*, chlorophyll *b* and total carotenoid used equations as recommended by Wellburn (1994), where chlorophyll *a*, C_a = ($12.21A_{663}–2.81A_{646}$), chlorophyll *b*, C_b = ($20.13A_{646}–5.03A_{663}$) and total carotenoid = ($1000A_{470}–3.27C_a– 104C_b$)/198. Total chlorophyll in plant tissues was expressed as $C_a + C_b$.

Leaf relative water content (LWRC) of each genotype was calculated at the same time of chlorophyll determinations. Sample leaves were weighed to get fresh mass (FM), washed with distilled water and floated in distilled water in a closed petridish for 24 hour, then weighed to get turgid mass (TM) and placed in vacuum oven at 80^{o}C for 48 hours to obtain dry mass (DM). LRWC was calculated as suggested by Lonbani and Arzani (2011), RLWC (%) = [(FM-DM)/(TM-DM)] x 100. Yields components were observed by means of fruit-length (cm, mean length of 30% harvested fruits), fruit diameter (mm, mean diameter of 30% harvested fruits); fruit-weight (g, average weight of 30% harvested fruits); and total fruit-weight per plant (g, average of total fruit-weight per sample plants). These were considered as the most reliable indicators to predict genetic superiority (Ganefianti *et al.*, 2012).

Coefficient correlations between leaf physiological traits and yield components of chili-pepper were calculated using Proc Corr SAS 9.1.3. The magnitude of correlations were determined by Hopkins (1997), where 0-0.10 (trivial, practically zero), 0.10- 0.30 (small), 0.30-0.50 (moderate, medium), 0.50-0.70 (large, high), 0.70-0.90 (very large, very high) and 0.90-1.00 (nearly perfect, perfect). Genotype effects on leaf physiological traits were calculated by Prog GLM SAS 9.1.3. Means of genotypes' physiological traits were compared using Duncan's Multiple Range Test at 95% level of confidence.

Results and Discussion

Coefficient correlations

The coefficient correlations between LPTs (chlorophyll *a*, chlorophyll *b*, ratio of chlorophyll *a* to chlorophyll *b*, and total chlorophyll, carotenoid, ratio of total chlorophyll to carotenoid as well as leaf relative water content) to fruit-length was generally higher at 10 WAT than those of 14 WAT (Table 1).

Table 1. Coefficient correlation between leaf physiological traits of chili-pepper genotypes grown in three types of soil at 10 and 14 weeks after transplanting (WAT) with fruit-length

Leaf physiological traits	Ultisol		Organosol		Regosol	
	10 WAT	14 WAT	10 WAT	14 WAT	10 WAT	14 WAT
Chlorophyll *a*	0.556*	0.213	-0.320	-0.282	-0.141	0.368
Chlorophyll *b*	0.339	0.107	-0.374	-0.240	0.022	0.151
Chlorophyll *a/b*	0.232	0.036	0.029	0.252	-0.241	-0.412
Total Chlorophyll	0.530*	0.168	-0.429*	-0.275	-0.092	0.276
Carotenoid	0.154	0.210	-0.274	-0.313	-0.244	0.098
Chlorophyll /Carotenoid	0.099	-0.005	-0.049	0.007	0.003	0.219
Leaf Relative Water Content	0.159	0.038	-0.053	0.362	-0.231	-0.028

*Note : * Significant at P < 0,05 according to Pearson's*

In Ultisol, at 10 WAT, the coefficient correlations of chlorophyll *a* and total chlorophyll to fruit-length were significantly high with the magnitudes of 0.556 and 0.530, respectively. This implies that these traits are convenient to predict fruit-length of chili pepper. However, in Organosol, correlation between total chlorophyll and fruit-length were negatively significant (-0.429). Negative correlation suggested that increased total chlorophyll decreased fruit-length of chili pepper. There were no significant correlations between LPTs in Regosol with fruit-length, implying that none of LPTs can be used to predict fruit-length of chili pepper grown in Regosol.

There were no significant correlations of all LPTs of chili pepper with fruit-diameter in Ultisol, Organosol and Regosol, except for leaf relative water content (LRWC) at 14 WAT and total chlorophyll in Organosol at 14 WAT (Table 2). However, the magnitude of these two significant traits were negative, i.e., -0.422 and -0.428, respectively. This suggested that low chlorophyll content and LRWC of chili pepper grown in Organosol reflected a high fruit-diameter.

Table 2. Coefficient correlation between leaf physiological traits of chili-pepper genotypes grown in three types of soil at 10 and 14 weeks after transplanting (WAT) with fruit diameter

Leaf physiological traits	Ultisol		Organosol		Regosol	
	10 WAT	14 WAT	10 WAT	14 WAT	10 WAT	14 WAT
Chlorophyll *a*	-0.380	-0.051	-0.320	-0.282	-0.236	0.074
Chlorophyll *b*	-0.228	-0.055	-0.374	-0.240	-0.309	-0.008
Chlorophyll *a/b*	-0.207	-0.039	0.029	0.252	0.050	-0.127
Total Chlorophyll	-0.362	-0.055	-0.428*	-0.275	-0.287	0.019
Carotenoid	0.046	0.070	-0.274	-0.313	0.096	-0.085
Chlorophyll /Carotenoid	-0.316	-0.108	-0.049	0.007	-0.219	0.099
Leaf Relative Water Content	0.251	-0.422*	-0.053	0.362	0.172	0.156

*Note : * Significant at P < 0,05 according to Pearson's*

The coefficient correlations between LPTs with fruit-weight were not significant both at 10 WAT and 14 WAT (Table 3), except for LRWC in Ultisol at 14 DAT and carotenoid in Organosol at 14 WAT. The magnitudes were negatively correlated, i.e., -0.433 and -0.453, respectively. These moderate magnitudes implied that fruit-weight of chili pepper grown in these types of soil decreased as its LPTs increased. Finally, the coefficient correlations between LPTs and fruit-weight per plant were not significant both at 10 WAT and 14 WAT and the magnitudes were generally higher at 10 WAT than those of 14 WAT (Table 4), except ratio chlorophyll *a/b* and LRWC in Organosol at 14 WAT. The magnitudes were 0.445 and 0.435, respectively, implying that fruit-weight of chili pepper per plant in Organosol can be moderately predicted by using ratio chlorophyll *a/b* and LRWC.

Table 3. Coefficient correlation between leaf physiological traits of chili-pepper genotypes grown in three types of soil at 10 and 14 weeks after transplanting (WAT) with fruit-weight

Leaf physiological traits	Ultisol		Organosol		Regosol	
	10 WAT	14 WAT	10 WAT	14 WAT	10 WAT	14 WAT
Chlorophyll *a*	-0.391	0.061	-0.155	-0.394	-0.312	0.163
Chlorophyll *b*	-0.201	0.084	-0.206	-0.322	-0.265	-0.062
Chlorophyll *a/b*	-0.253	-0.108	-0.037	0.181	-0.111	-0.259
Total Chlorophyll	-0.361	0.076	-0.219	-0.381	-0.324	-0.001
Carotenoid	-0.046	0.019	-0.144	-0.453*	0.008	-0.113
Chlorophyll /Carotenoid	-0.223	0.035	-0.054	0.051	-0.290	0.112
Leaf Relative Water Content	0.209	-0.433*	0.105	0.337	0.096	0.253

*Note : * Significant at P < 0,05 according to Pearson's*

Table 4. Coefficient correlation between leaf physiological traits of chili-pepper genotypes grown in three types of soil at 10 and 14 weeks after transplanting (WAT) with fruit-weight per plant

Leaf physiological traits	Ultisol		Organosol		Regosol	
	10 WAT	14 WAT	10 WAT	14 WAT	10 WAT	14 WAT
Chlorophyll *a*	0.071	-0.185	0.042	-0.242	-0.202	0.368
Chlorophyll *b*	0.368	-0.182	-0.260	-0.294	-0.331	-0.007
Chlorophyll *a/b*	-0.308	0.086	0.250	0.454*	0.077	-0.277
Total Chlorophyll	0.172	-0.191	-0.097	-0.258	-0.271	0.125
Carotenoid	-0.116	-0.115	-0.087	-0.071	0.165	-0.042
Chlorophyll /Carotenoid	0.201	0.129	0.002	-0.215	-0.359	0.253
Leaf Relative Water Content	-0.086	0.219	-0.335	0.435*	-0.007	-0.003

*Note : * Significant at P < 0,05 according to Pearson's*

Results from these experiments suggested that chlorophyll *a* can be conveniently used to predict fruit-length in Ultisol. Meanwhile, total chlorophyll can be conveniently used to predict fruit-length in Ultisol and Organosol, and to predict fruit-diameter in Organosol. Furthermore, carotenoid concentration can be used to predict fruit-weight in Organosol, while ratio of chlorophyll *a* to chlorophyll *b* can be used to predict fruit-weight per plant. Lastly, LRWC can be used to predict fruit-diameter and fruit-weight in Ultisol, and to predict fruit-weight per plant in Organosol. These results were in accordance with Koolachart *et al*. (2013) who concluded that high chlorophyll and LRWC were proportional to increased number of pods per plant in peanut. Research conducted by Chaghanakaboodi *et al.* (2012) also revealed that LRWC is proportional to increased of grain yield. However, our results did not find any significant correlation between chlorophyll *b* to yield components of chili peppers. This was unlikely similar to what was reported by Sharifi *et al.* (2012) who concluded that there was a positive correlation between chlorophyll *b* concentration and yield of wheat. Sibomana *et al*. (2013) reported that increased fruit-diameter of tomato was proportional to increased of total chlorophyll and LRWC. These were contrary to our results where total chlorophyll and LRWC had negative correlation with fruit-diameter of chili pepper grown in Organosol and Ultisol, respectively.

Soil type determines nutrient availability for many crops. According to Tesfaw *et al*. (2013) nutrient availability in the soil and growing location significantly affects total fruit-weight per plant of hot pepper. Conclusively, each soil type requires particular leaf physiological traits served as a detector to predict yield of chili pepper. Our findings also revealed that the magnitude of coefficient correlations for all leaf physiological traits were generally higher at 14 WAT than those of at 10 WAT. Weakening the magnitudes of correlations suggested that determination of leaf physiological traits should be established during the earlier stage of plant growth, *i.e.,* before 10 WAT to generate reliable prediction. In addition, estimations should be conducted prior to flowering to provide reliable predictions since leaf chlorophyll tended to decline as plant continue to grow in most flowering plants.

Leaf physiological traits

Chlorophyll *a* concentrations of chili pepper genotypes in Ultisol at 10 WAT were significantly different to one another, but not at 14 WAT (Table 5). At 10 WAT, among all the promising genotypes (H13, H23, H43, H53 and H73), genotypes of H53 had the highest chlorophyll *a* concentrations, followed by H23 and H13 genotypes. Chlorophyll *a* concentrations of H53 genotype was similar to both parent genotype (P3) and commercial hybrid of Tilala, but higher than commercial hybrid of IPBCH3. In Organosol, both at 10 and 14 WAT, there were significant differences in chlorophyll *a* concentrations among the promising genotypes. At 10 WAT chlorophyll *a* concentrations of H13 was the highest among promising genotypes. But at 14 WAT, H43 genotype had the highest chlorophyll *a* concentrations. In Regosol, H53 genotypes had the highest chlorophyll *a* concentrations at 10 WAT, followed by H43 and H13 genotypes. At 14 WAT, however, H73, H53 and H43 had the highest chlorophyll *a* concentrations among the promising genotypes.

Table 5. Chlorophyll *a* concentration of 8 genotypes chili peppers at 10 and 14 weeks after transpanting (WAT) grown in three different types of soils (µmol/L).

Genotypes	Ultisol		Organosol		Regosol	
	10 WAT	14 WAT	10 WAT	14 WAT	10 WAT	14 WAT
H13	3.664 bc	1.314	4.432 a	1.631 b	3.360 ab	1.318 a
H23	3.909 bc	0.714	3.262 bc	0.844 b	2.559 b	1.259 ab
H43	3.360 c	0.738	3.257 bc	5.747 a	3.091 ab	0.544 c
H53	4.819 ab	0.717	3.210 bc	0.994 b	4.016 a	0.540 c
H73	2.876 c	1.264	3.302 bc	0.831 b	2.754 b	0.829 c
P3	5.537 a	1.279	3.912 ab	1.016 b	2.528 b	0.848 bc
IPBCH3	3.040 c	1.047	2.860 c	0.658 b	2.574 b	0.782 c
Tilala	4.033 bc	0.539	2.501 c	5.007 a	3.019 ab	0.891 bc
Prob. Value > F (5%)	0.0026	0.1772	0.0064	0.0008	0.0883	0.0057
Model (Prob. > F)	0.0051	0.1310	0.0044	0.0018	0.1176	0.0102
Coefficient of variances	16.57	42.70	14.15	62.51	19.57	25.69

Note : Means in the same column followed with the same letter are not significantly different according Duncan's Multiple Range Test at 5%

Trends of chlorophyll *b* concentrations of chili-pepper genotypes were generally similar to those in chlorophyll *a* (Table 6). Chlorophyll *b* concentrations of chili pepper genotypes in Ultisol at 10 WAT were significantly different to one another, but not at 14 WAT (Table 6). At 10 WAT, among all promising genotypes, H53 had the highest chlorophyll *b* concentrations, followed by H23, H13 and H43 genotypes. Chlorophyll *a* concentrations of H53 genotype was similar to both parent genotype (P3) and commercial hybrids of IPBCH3, but higher than commercial hybrid of Tilala. In Organosol, both at 10 and 14 WAT, there were significant differences in chlorophyll *b* concentrations among the promising genotypes. At 10 WAT chlorophyll *b* concentrations of H73 was the highest among promising genotypes. But at 14 WAT, H43 genotype had the highest chlorophyll *b* concentrations. In Regosol, both at 10 and 14 WAT, H53 had the highest chlorophyll *b* concentrations among the promising genotypes.

Table 6. Chlorophyll *b* concentration of 8 genotypes chili peppers at 10 and 14 weeks after transpanting (WAT) grown in three different types of soils (µmol/L).

Genotypes	Ultisol		Organosol		Regosol	
	10 WAT	14 WAT	10 WAT	14 WAT	10 WAT	14 WAT
H13	2.032 abc	1.141 ab	1.501 a	1.092 bc	1.791 ab	0.893 bc
H23	2.140 ab	0.465 bc	1.306 abc	0.550 c	1.235 c	1.094 b
H43	1.955 abc	0.758 abc	0.960 bc	2.085 a	1.326 bc	0.168 d
H53	2.435 a	0.469 bc	0.803 bc	0.356 c	2.229 a	3.028 a
H73	1.490 c	1.250 a	1.435 ab	0.530 c	1.517 bc	0.462 cd
P3	2.462 a	0.978 abc	1.683 a	0.473 c	1.564 bc	0.467 cd
IPBCH3	1.663 bc	0.852 abc	0.700 c	0.507 c	1.514 bc	0.469 cd
Tilala	1.533 c	0.373 c	1.151 abc	1.529 ab	1.786 ab	0.601 cd
Prob. Value > F (5%)	0.0048	0.0594	0.0462	0.0060	0.0097	0.0001
Model (Prob. > F)	0.0105	0.0496	0.0251	0.0117	0.0147	0.0001
Coefficient of variances	14.85	44.81	30.21	55.30	16.12	26.99

Note : Means in the same column followed with the same letter are not significantly different according Duncan's Multiple Range Test at 5%

Ratios of chlorophyll *a* to chlorophyll *b* of 8 chili peppers' genotypes at 10 and 14 WAT were not significant in Ultisol, Organosol, and Regosol , except those of grown in Regosol at 14 WAT (Table 7). At 14 WAT in Regosol, H43 had the highest chlorophyll *a* chlorophyll *b* ratio, and H53 had the lowest ratio. However, there were significantly different of total chlorophyll of chili pepper genotypes both at 10 and 14 WAT (Table 8), except those of 14 WAT in Ultisol. Genotypes H53 had the highest chlorophyll content in Ultisol and Regosol, meanwhile genotype H43 had the highest chlorophyll content in Organosol. In addition, carotenoid concentrations in chili pepper were significantly different among tested genotypes at 10 WAT in all soil types. At 14 WAT, however, there were significantly different in carotenoid content of all genotypes of chili pepper in all soil types (Table 9). At 14 WAT, among the promising genotypes, H53 had the highest carotenoid concentration in Ultisol and Regosol. In Organosol, H43 had the highest concentration, followed by H53 genotype.

Carotenoid concentrations of chili pepper of each genotype in all soil types were generally increased as plant continued to grow.

Table 7. Ratio of chlorophyll *a* to chlorophyll *b* of 8 genotypes chili peppers at 10 and 14 weeks after transpanting (WAT) grown in three different types of soils

Genotypes	Ultisol		Organosol		Regosol	
	10 WAT	14 WAT	10 WAT	14 WAT	10 WAT	14 WAT
H13	1.808 ab	1.141	3.548	1.520	1.871	1.505 bc
H23	1.852 ab	1.685	2.607	1.662	2.069	1.146 bc
H43	1.717 b	0.853	3.648	2.770	2.539	4.596 a
H53	1.981 ab	1.603	7.592	5.167	1.804	0.179 c
H73	1.936 ab	1.018	2.295	2.236	1.807	1.831 bc
P3	2.252 ab	1.306	4.272	2.611	1.622	2.183 b
IPBCH3	1.881 ab	1.535	2.359	5.167	1.688	1.758 bc
Tilala	2.739 a	2.653	2.464	3.527	1.699	1.694 bc
Prob. Value > F (5%)	0.2850	0.3371	0.4215	0.7018	0.3097	0.0021
Model (Prob. > F)	0.3846	0.3591	0.2757	0.4620	0.2630	0.0048
Coefficient of variances	24.05	72.96	81.70	98.84	23.68	47.56

Note : Means in the same column followed with the same letter are not significantly different according Duncan's Multiple Range Test at 5%

Table 8. Total chlorophyll of 8 genotypes chili peppers at 10 and 14 weeks after transpanting (WAT) grown in three different types of soils (μmol/L).

Genotypes	Ultisol		Organosol		Regosol	
	10 WAT	14 WAT	10 WAT	14 WAT	10 WAT	14 WAT
H13	5.696 cd	2.455	5.933 a	2.724 b	5.150 ab	2.210 bc
H23	6.049 bc	1.179	4.568 cd	1.500 b	3.794 b	2.353 b
H43	5.315 cd	1.497	4.217 cd	7.832 a	4.417 b	0.712 d
H53	7.255 ab	1.189	4.013 cd	1.350 b	6.245 a	3.568 a
H73	4.366 d	2.514	4.737 bc	1.362 b	4.275 b	1.291 d
P3	7.999 a	2.257	5.595 ab	1.489 b	4.092 b	1.314 d
IPBCH3	4.703 cd	1.899	3.560 d	1.165 b	4.087 b	1.251 d
Tilala	5.565 cd	0.911	3.653 d	6.537 a	4.805 b	1.491 cd
Prob. Value > F (5%)	0.0008	0.0751	0.0007	0.0011	0.0388	0.0001
Model (Prob. > F)	0.0017	0.0547	0.0007	0.0025	0.0242	0.0001
Coefficient of variances	13.28	40.28	11.95	58.28	16.06	24.83

Note : Means in the same column followed with the same letter are not significantly different according Duncan's Multiple Range Test at 5%

Table 9. Carotenoid content of 8 genotypes chili peppers at 10 and 14 weeks after transpanting (WAT) grown in three different types of soils (µmol/L).

Genotypes	Ultisol		Organosol		Regosol	
	10 WAT	14 WAT	10 WAT	14 WAT	10 WAT	14 WAT
H13	0.264	0.453 b	0.445	0.357 b	0.270	0.954 ab
H23	0.387	0.263 cd	0.299	0.487 b	0.338	0.533 ab
H43	0.263	0.209 d	0.304	1.041 a	0.487	0.268 c
H53	0.517	0.628 a	0.315	0.718 ab	0.162	1.439 a
H73	0.291	0.323 bcd	0.212	0.344 b	0.283	0.268 c
P3	0.457	0.426 bc	0.399	0.617 ab	0.196	0.522 bc
IPBCH3	0.403	0.442 bc	0.329	0.307 b	0.287	0.509 bc
Tilala	0.440	0.370 bcd	0.383	1.008 a	0.275	0.476 bc
Prob. Value > F (5%)	0.6113	0.0034	0.2719	0.0150	0.5343	0.0129
Model (Prob. > F)	0.6882	0.0035	0.3272	0.0317	0.3901	0.0269
Coefficient of variances	49.44	24.77	31.19	42.18	61.33	54.71

Note : Means in the same column followed with the same letter are not significantly different according Duncan's Multiple Range Test at 5%

These experiments also revealed that ratios of chlorophyll to carotenoid in all soil types, both at 10 and 14 WAT were not significantly different among the tested genotypes, except of Regosol at 10 WAT (Table 10). At 10 WAT in Regosol, genotypes H53 had the highest ratio of chlorophyll to carotenoid. In addition, there were significantly different in Leaf Relative Water Content (LRWC) of tested chili pepper genotypes in all types of soils both at 10 and 14 WAT (Table 11), except at 10 WAT in Ultisol and Organosol. Both H73 and H53 had the highest LRWC at 14 WAT in Ultisol, followed by H13 genotype. H73 genotype seemed to consistently have the highest LRWC in all soil types both at 10 and 14 WAT. All LRWCs, however, at 14 WAT were generally lower than those in 10 WAT.

Table 10. Ratio of chlorophyll to carotenoid of 8 genotypes chili peppers at 10 and 14 weeks after transpanting (WAT) grown in three different types of soils

Genotypes	Ultisol		Organosol		Regosol	
	10 WAT	14 WAT	10 WAT	14 WAT	10 WAT	14 WAT
H13	21.64	5.48	13.52	8.02	21.19 b	3.43
H23	17.07	5.97	17.22	3.08	11.43 b	4.54
H43	20.35	6.92	15.02	8.56	17.99 b	2.81
H53	16.78	1.91	14.21	2.11	40.29 a	2.55
H73	15.16	7.92	24.01	3.85	18.47 b	6.17
P3	19.48	5.81	15.33	2.40	21.01 b	2.46
IPBCH3	13.43	4.15	11.04	6.70	15.78 b	2.59
Tilala	15.84	2.59	9.35	5.97	18.19 b	3.08
Prob. Value > F (5%)	0.7211	0.2009	0.0987	0.1001	0.0440	0.2105
Model (Prob. > F)	0.7098	0.2369	0.0745	0.134	0.0376	0.2759
Coefficient of variances	34.81	54.83	32.79	58.74	42.55	50.91

Note : Means in the same column followed with the same letter are not significantly different according Duncan's Multiple Range Test at 5%

Table 11. Leaf Relative Water Content of 8 genotypes chili peppers at 10 and 14 weeks after transpanting (WAT) grown in three different types of soils (%)

Genotypes	Ultisol		Organosol		Regosol	
	10 WAT	14 WAT	10 WAT	14 WAT	10 WAT	14 WAT
H13	70.838	68.45 ab	68.29	71.22 abc	84.74 a	71.23 abc
H23	76.351	59.90 bc	74.02	72.01 abc	83.44 a	72.02 abc
H43	74.710	59.44 bc	73.02	67.95 bc	78.19 a	67.95 bc
H53	73.950	77.80 a	69.38	68.63 bc	65.25 b	68.63 bc
H73	70.582	78.48 a	75.76	78.87 a	82.29 a	78.87 a
P3	78.144	57.09 bc	67.48	66.85 bc	83.52 a	66.85 bc
IPBCH3	78.653	47.21 c	74.95	76.39 ab	77.67 a	76.39 ab
Tilala	75.668	71.15 ab	79.79	61.83 c	79.54 a	61.83 c
Prob. Value > F (5%)	0.3214	0.0128	0.7088	0.0316	0.0397	0.0316
Model (Prob. > F)	0.3878	0.0057	0.7582	0.0397	0.0749	0.0397
Coefficient of variances	6.11	13.16	12.41	7.92	7.95	7.49

Note : Means in the same column followed with the same letter are not significantly different according
Duncan's Multiple Range Test at 5%

According to Elshafei *et al*. (2013), chlorophyll *a*, chlorophyll *b*, total chlorophyll, ratio between chlorophyll *a* to chlorophyll *b*, carotenoid content and ratio between chlorophyll and carotenoid are very sensitive to environmental stresses and thylakoid membrane stability. So does LRWC content that closely related to leaf turgor, growth, stomatal conductance, transpiration, photosynthesis and respiration (Kramer and Boyer, 1995). The higher these content plant leaves, the more adaptive such plant to new growing environment. Research conducted by Koolachart *et al.* (2013) concluded that high chlorophyll and LRWC in peanut could maintain high number of pods per plant. Decreasing values of all observed leaf physiological traits as plant got older might related to aging of chili pepper. Hendry and Price (1993) suggested that plant's pigments decreased as plants continue to grow.

In conclusions, this study concluded that some LPTs can be used to predict chili pepper adaptability to three different types of soils. Chlorophyll *a* can be positively used to predict fruit-length in Ultisol. Chlorophyll *a/b* can be positively used to predict fruit-weight per plant in Organosol. Total chlorophyll can be positively used to predict fruit-length in Ultisol, but can be negatively used to predict fruit-length and fruit-diameter in Organosol. Carotenoid can be negatively used to predict fruit-weight in Organosol. LRWC can be negatively used to predict fruit-diameter and fruit-weight in Ultisol, but can be positively to predict fruit-weight per plant in Organosol. Chlorophyll *b* can not be used to predict fruit-length, fruit-diameter, fruit-weight, and fruit-weight per plant in all type of soils. There were no LPTS can be used to predict fruit-length, fruit diameter, fruit-weight, and fruit-weight per plant in Regosol. In terms of genotype adaptability to three different type of soil, H53 was the most suitable genotype in Ultisol, followed by H13. In Organosol, H43 was the most suitable genotype, followed by H13. In Regosol, H53 was the most suitable genotype, followed by H13. Overall, H13 was a wide range genotype that adaptive to Ultisol, Organosol, and Regosol.

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