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COMPARISON OF METHODS FOR DRY MATTER CONTENT DETERMINATION IN POTATO USING MULTI-ENVIRONMENTS FIELD DATA AND STABILITY STATISTICS

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ABSTRACT

Tuber dry matter content (TDM) is considered as the main determinant of processed potato tuber quality. In order to investigate rapid, practicable and reliable methods for the measurement of TDM, a study was planned to compare three standard methods (digital potato hydrometer, moisture-drying on quartz seasand and oven-dry) among 189 diverse potato genotypes, grown under three environmental conditions (Hatay "standard water application", Konya "standard water application" and Konya "drought" conditions). ANOVA revealed highly significant differences (p<0.01) in all treatments among tests, checks and tests vs check genotypes. Environmental conditions significantly affect the TDM, while methods showed differential response within the tested environments. A strong correlation (r) and high goodness of fit (R^2) was observed between seasand and hydrometer methods as compared to oven-dry method. Wide applicability and reliability of seasand and hydrometer methods were also confirmed by stability statistics. This study recommends seasand as an accurate and hydrometers as rapid method in contrast to oven dry method for the measurement of TDM. Parametric stability methods such as bi and S^2_{di} identified stable genotypes with optimum TDM, that can serve as a useful resource for breeding of processing cultivars.

Keywords: Hydrometer, potato, oven-dry, seasand method, stability, tuber dry matter content

INTRODUCTION

Potato (*Solanum tuberosum* L.) is the third most substantially produced and consumed tuber crop around the globe with 1.3 billion people consuming it as a staple food crop (more than 50 kg/person/year) (Devaux et al., 2020). The sensory characteristics of potato such as taste, colour and aroma of tubers are altered during cooking, mainly due to the changes in tuber compositional traits. Dry matter (DM) content is one of the major quality traits of potato alongside with starch, reducing sugars and proteins (Van Eck, 2007). It is an early determinant of tuber quality and influence the final yield of processed tuber products (chips/crisps and French fries). Studies revealed that high DM and low reducing sugars increases the crispy consistency of chips, decreases oil absorption while cooking, reduces bitter taste and dark colour of processed tuber products (Peiris et al., 1999; Asmamaw et al., 2010). Generally, the processing industry does not accept the tuber dry matter content (TDM) below 19.5% for French fries and 20% for chips. Upper limits do not apply, though penalties may be incurred for DM content more than 25% (McGregor, 2007). Selection of stable genotypes with optimum DM content is a major objective in potato breeding programmes aimed at improving processing tuber quality (Neele and Louwes, 1989). Genotypes and growing conditions may affect the DM content. Cultivars with high DM has better quality characteristics as compared to their lower counterpart (Asmamaw et al., 2010). Environmental conditions such as availability of moisture, temperature and soil characteristics have a profound effect on tuber quality (Kumar et al., 2004; Sharma et al., 2011). Stability statistics not only unveil the performance of genotypes in various environments, but reliability and feasibility of methods can also be compared. Two growing seasons i.e., early (Mediterranean climate) and seasonal (Continental climate) are practiced for potato production in Turkey. Owing to the differences in climate, it is inevitable to evaluate the tuber dry matter content of diverse genotypes in different climatic zones.

Potato constituents are not evenly distributed within and between tubers. Percentage of DM content in tubers is highest in the inner cortical region while skin and pith have lowest DM. In this context, destructive and non-destructive methods of DM measurement assumed to cause disparity. Several methods have been cited to measure the DM content of potatoes. Saini (1964) gave an assumption that DM content of potato is a linear function of weight in water rather than specific gravity of tuber. On the contrary, Schippers (1976) stated that specific gravity had a strong correlation with DM content. Method of oven drying (gravimetric method) has been discussed by scientists such as Caliskan et al. (2004), Bonierbale (2007), Asmamaw et al. 2010, Mebratie and Desta (2018) and Camps and Camps (2019). Moisture-drying on quartz seasand or moisture-air oven method have also been utilized to analyse the DM content (AACC, 1993a, 1993b; Haase, 2003, 2011). Furthermore, under-water weight measurement (hydrometer) was also practiced estimating the DM content in potatoes (Van Dijk et al., 2002; Haase, 2003; Kumar et al., 2005; Ozkaynak et al., 2018). These methods were used solely by researchers, but their comparative efficacy and feasibility in diverse genotypes under different environmental conditions have not been assessed so far. The measurement of DM content through calibrated models developed by NIRS (Near Infrared Spectroscopy) and MRI (magnetic resonance imaging) techniques faced several shortcomings in terms of reproducibility and overlapping absorbance due to high water content (upto 80%) in fresh potatoes (Hansen et al., 2010; Haase, 2011). Furthermore, NIRS and MRI techniques needs to be compared and calibrated with accurate and reliable results from one of the standard methods. Thus, evaluation of destructive and non-destructive standard methods is a painstaking challenge for the stable outcome of DM under various environmental conditions.

The objective of this study was to evaluate the practicability and reliability of standard methods under various environmental conditions to measure the TDM of diverse potato genotypes. Statistical tools were used to unveil the strength of standard methods. Stability statistics were performed to identify the stable genotypes with an optimum TDM.

MATERIALS AND METHODS

Plant materials and experimental plan

A total of 189 tetraploid potato genotypes (83 from German breeding company, 83 from Turkish breeding company, 18 processing genotypes in both countries and 5 check cultivars) were selected for the analysis of TDM. The check cultivars were Agria, Hermes, Jelly, Rumba and Alegria. All potato genotypes included in the study were grown under three different environmental conditions; (Hatay “standard water application”; Konya “standard water application” and Konya “drought conditions”) during the year 2018. The province of Hatay (36.26° N, 36.56° E, 183 m elevation) constitutes a Mediterranean climate and represents an early potato production area. The area has a characteristic clay silt loam soil with pH of 7.6. Contrarily, the province of Konya (37.87° N, 32.49° E, 1016 m elevation) is the major potato production area with continental climate. The experimental site has sandy clay loam soil with a pH of 8.1. Temperature and relative humidity during growing season are shown in Table 1. The field trials were planted by using augmented block design (Petersen, 1985) in blocks of 25 genotypes with five check cultivars in each block, in each environmental condition. Each plot consists of two rows 75 cm apart, having 25 plants per row at each site, with plant to plant distance of 30 cm. Standard potato production practices were followed during the growing period at each site. After harvesting, the tubers of each genotype were collected and stored at +8 ⁰C with RH (relative humidity) of 95%. The variable TDM was examined through different methods as discussed below.

Table1. Description of temperature (°C) and relative humidity (RH%) during growing season.

Hatay 2018 (early)			**Konya 2018 (seasonal)**		
Months	High/low (°C)	RH[a] (%)	Months	High/low (°C)	RH (%)
January	15/0	75	April	26/1	48
February	18/0	76	May	27/6	59
March	25/4	68	June	33/11	51
April	28/4	55	July	35/14	41
May	30/11	59	August	34/14	36
			September	33/9	43

RH[a] = Relative humidity

Methods for the measurement of tuber dry matter content

TDM of 189 genotypes were measured by three methods; (i) Martin Lishmans's digital potato hydrometer (based on under water weight measurement principle), (ii) oven-dried method and (iii) moisture-air oven method (AACC, 1993a; Haase, 2003) also referred to as seasand method. The first two methods were employed in all three environmental conditions for each genotype included in the study, while seasand method was implemented for further in-depth analysis of TDM in Konya “standard water application” and Konya “drought conditions” for the same number of genotypes. The determination of TDM through hydrometer was carried out with a subsample of around 2500 g clean unpeeled raw tubers from each genotype replicated three times. It is a non-destructive method of TDM measurement in contrast to two other destructive methods discussed below.

In oven-dry method, 5 to 8 raw tubers (randomly selected) were peeled, chopped and put in three aluminium boxes. Fresh weight of tuber samples was taken by using electronic balance. Later, samples were oven dried at 90 ºC for 16h. Dried tuber samples were weighed again. Each genotype was replicated thrice. TDM% was calculated by formula:

TDM% for oven-dried method = Oven dry weight / initial fresh weight × 100

In moisture-air oven or quartz seasand method, 5 to 8 raw tubers were selected at random from each genotype. Tubers were cleaned under tap water and outer skin was dried prior to analysis. Tubers were sliced and later an aliquot of around 350 g was homogenized (mash) with a kitchen mixer. Dry quartz seasand was taken in petri dishes along with stirrer and weighed. 2.5 g to 5.0 g of homogenized tuber mash was placed in a petri dish and weighed along with stirrer. Sample was dried in an oven at 105 ºC for 15h, subsequently cooled down in a desiccator and weigh again on sensitive electronic balance. All measurements were replicated three times. The TDM% was calculated by formula:

TDM% = (Oven dry weight of seasand + stirrer + sample (g) – weight of seasand + stirrer (g)) × 100 / (weight of seasand+stirrer + sample (g) – weight of seasand+stirrer (g))

Statistical analyses

Treatment data set comprised of methods and environments for 189 diverse genotypes. SAS, version 9.0 statistical package was used for augmented block design analysis to get an estimated value of each treatment. PROC GLM codes were used for analysis of variance as stated by Wolfinger et al. (1997) in SAS software. Same statistical package was used to calculate correlation and regression among set of treatments. The estimated values obtained after SAS software analysis were further analysed by using Microsoft Excel plugin Analyse-it® to find out correlation scatter matrix. Same estimated values were utilized in AMMISOFT to investigate genotype by environment interactions (GEI) for TDM considering methods as replicates. AMMI combines ANOVA into a single model with additive and multiplicative parameters (Gauch and Moran, 2019). Parametric stability statistics such as regression coefficient (*bi*) (Finlay and Wilkinson, 1963) and variance of deviations from the regression (S^2_{di}) (Eberhart and Russell, 1966) were calculated through STABILITYSOFT (Pour-Aboughadareh et al., 2019).

RESULTS

Analysis of variance

The analysis of variance (ANOVA) for 189 genotypes depicting the mean squares, MSE (mean squared error) and CV% (coefficient of variation) for the set of treatments encompassing environmental conditions and methods, to measure the TDM is delineated in Table 2. ANOVA revealed highly significant differences ($p<0.01$) for all treatments (environments-methods) among tests, checks (control) and tests vs check genotypes. Since, checks were standard cultivars, their effects were fixed. While blocks, new entries (test genotypes) and error were considered as random effects. The significance among tests and check genotypes disclosed the presence of variability, which allows the selection of genotypes with optimum, and stable TDM across tested environments. Statistical description of TDM in set of treatments is given in Table 3. Wide variation of TDM showed diversity in genotypes as indicated by minimum and maximum values.

Table 2. Mean squares and their significance for set of treatments (environments-methods) of 189 genotypes for variable TDM% (tuber dry matter content in percent).

	MEAN SQUARES					
Environments-Methods	**Block (7)**	**Among checks (4)**	**Among Test genotypes (183)**	**Checks vs Test genotypes (188)**	**Error**	**CV%**
HS-H	0.86	12.79**	6.42**	7.32**	1.107	11.59
HS-O	4.12	19.84**	8.66**	9.77**	1.632	13.06
KS-H	0.66	6.55**	6.03**	6.48**	0.818	11.18
KS-SS	0.50	11.30**	7.94**	8.50**	0.550	12.98
KS-O	0.13	17.30**	8.37**	9.23**	0.767	12.51
KD-H	1.89	11.35**	6.78**	7.20**	0.977	10.80
KD-SS	0.57	9.43**	7.25**	7.88**	0.989	11.21
KD-O	0.31	8.87**	10.81**	11.40**	0.498	13.10

Table 3. Descriptive statistics of variable tuber dry matter content.

Environments-Methods	Number of genotypes	Mean (%) ± SEM	Minimum	Maximum
HS-H	189	21.708 ± 0.194	15.810	29.430
HS-O	189	22.445 ± 0.219	13.579	29.832
KS-H	189	20.929 ± 0.182	15.447	29.987
KS-SS	189	20.585 ± 0.209	16.797	31.882
KS-O	189	20.885 ± 0.216	15.990	30.291
KD-H	189	24.246 ± 0.195	17.986	33.468
KD-SS	189	24.344 ± 0.201	16.923	34.501
KD-O	189	24.735 ± 0.242	15.198	34.21

In an augmented analysis, the variation in test genotypes can be assessed by the variation among the check cultivars. The mean estimated values of each check cultivar (Agria, Alegria, Hermes, Jelly, Rumba) showed significant difference in each set of treatments (Figure 1). Cultivars, Rumba and Hermes showed high dry matter content compared to other three check cultivars except Alegria, which was statistically at par with Hermes under Konya drought conditions. Alegria and Agria recorded same TDM under Hatay standard water conditions. Alegria also showed statistically same TDM in Hatay and Konya standard water conditions and may be regarded as stable genotype. Drought conditions depicted high dry matter content in all check cultivars, when compared to standard water conditions in Konya. The graph disclosed that environmental conditions significantly affect the TDM. Discrepancy was observed among the TDM determination methods within the environments. Same trend was observed in test genotypes (Table 3 & Figure 1). Further, statistical tools such as correlation, and regression were performed to dissect the methods within each environment.

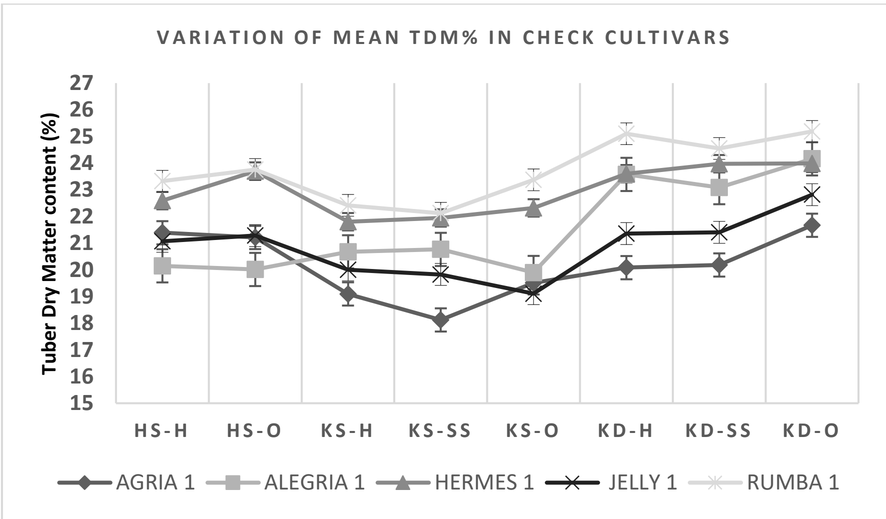

Figure 1. Mean TDM% variation in check cultivars (Agria, Alegria, Hermes, Jelly, Rumba) in a set of treatments.
Acronyms: HS-H (Hatay Standard water application-Hydrometer method); HS-O (Hatay Standard water application-Oven method); KS-H (Konya Standard water application-Hydrometer method); KS-SS (Konya Standard water application-Seasand method); KS-O (Konya Standard water application-Oven method); KD-H (Konya Drought-Hydrometer method); KD-SS (Konya Drought-Seasand method); KD-O (Konya Drought-Oven method).

Comparison of methods by correlation analysis and scatter matrix

The results of Pearson correlation coefficient (r) among the set of treatments (environments-methods) for the variable tuber dry matter content (TDM) are summarized in Table 4. It was observed that all correlations (r) were highly significant (p<0.01). It means that null hypothesis was rejected and thus concluded that population correlation coefficient (ρ) was not equal to zero. Results showed significant strong correlation of r=0.892 and r=0.882 between seasand and hydrometer methods in Konya standard water application and Konya drought conditions, respectively. Though, a correlation of r=0.849 was recorded between oven-dry and hydrometer methods in Hatay standard water application, but comparatively weaker "*r"* values of 0.656 and 0.606 were observed with same methods, in Konya standard water and drought conditions, respectively. Interestingly, oven-dry method showed r=0.739 and r=0.749 with hydrometer and seasand methods, respectively under Konya drought conditions. Weak to moderate correlations were present among the different environmental conditions. It could possibly explain the variation of TDM in different environmental conditions, while all three methods were comparable to each other. Correlation scatter matrix displaying the graphical illustration of pairwise scatter plot is presented in Figure 2. Much scattering of clusters was observed, when oven-dry method was taken as abscissa and/or as ordinate, in contrast to two other methods. Pearson correlation coefficient also showed similar findings by exhibiting strong correlation between hydrometer and seasand methods.

Table 4. Correlation (r) among the set of treatments (environments-methods) for variable tuber dry matter content.

Pearson correlation coefficients, N = 189 Prob > |r| under H_0: ρ =0								
	HS-H	HS-O	KS-H	KS-SS	KS-O	KD-H	KD-SS	KD-O
HS-H	1	0.849**	0.667**	0.651**	0.535**	0.622**	0.580**	0.394**
HS-O		1	0.656**	0.617**	0.451**	0.607**	0.568**	0.421**
KS-H			1	0.892**	0.710**	0.768**	0.741**	0.580**
KS-SS				1	0.752**	0.775**	0.731**	0.577**
KS-O					1	0.675**	0.598**	0.480**
KD-H						1	0.882**	0.739**
KD-SS							1	0.749**
KD-O								1

Prob=Probability; H_0 = Null hypothesis; ρ = correlation; **significant at p<0.01; *CV% = Coefficient of variation in percent.*
Acronyms: HS-H (Hatay Standard water application-Hydrometer method); HS-O (Hatay Standard water application-Oven method); KS-H (Konya Standard water application-Hydrometer method); KS-SS (Konya Standard water application-Seasand method); KS-O (Konya Standard water application-Oven method); KD-H (Konya Drought-Hydrometer method); KD-SS (Konya Drought- Seasand method); KD-O (Konya Drought-Oven method).

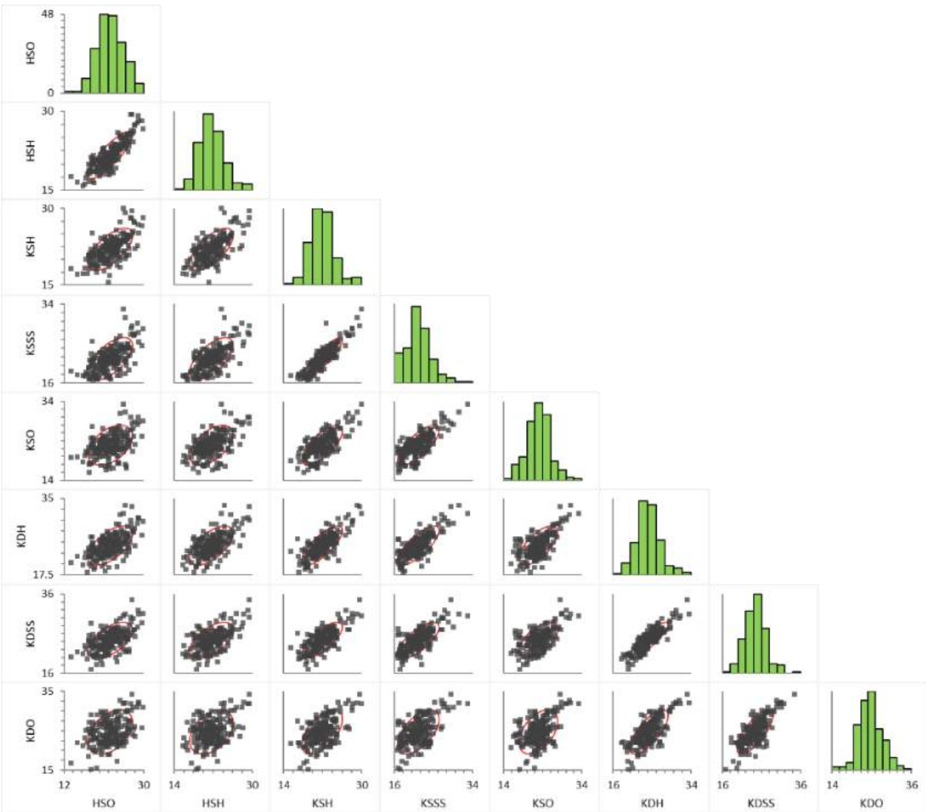

Figure 2. Correlation scatter matrix of variable tuber dry matter content (%) measured through hydrometer, oven dry method and moisture-air oven (sea-sand) method under three environmental conditions.

Comparison of methods by regression analysis

Regression analysis were performed to unveil the strength of variable methods under different environmental conditions (Figure 3). The Figure 3 showed fitted linear regression model along with coefficient of determination (R^2). The graphs revealed that the maximum values of R^2=0.796 and R^2=0.776, were recorded with hydrometer and seasand methods, under Konya standard water and drought conditions. According to fitted model, it implies that 79.64% and 77.63% of variance in the hydrometer method can be explained by seasand method. Relatively less R^2 values were obtained, when oven method was compared to seasand and hydrometer methods. Though 72.15% variance was explained by the model, in case of oven method, when compared to hydrometer under Hatay standard water conditions, but the same method showed relatively low goodness of fit (R^2=50.90% and R^2=63.29%) under Konya standard water and Konya drought conditions, respectively. So, an efficacy of oven dry method was affected by the shift in environment. A total of 56.94% and 66.83% variance was justified by oven method in comparison to seasand method under Konya standard water and drought conditions.

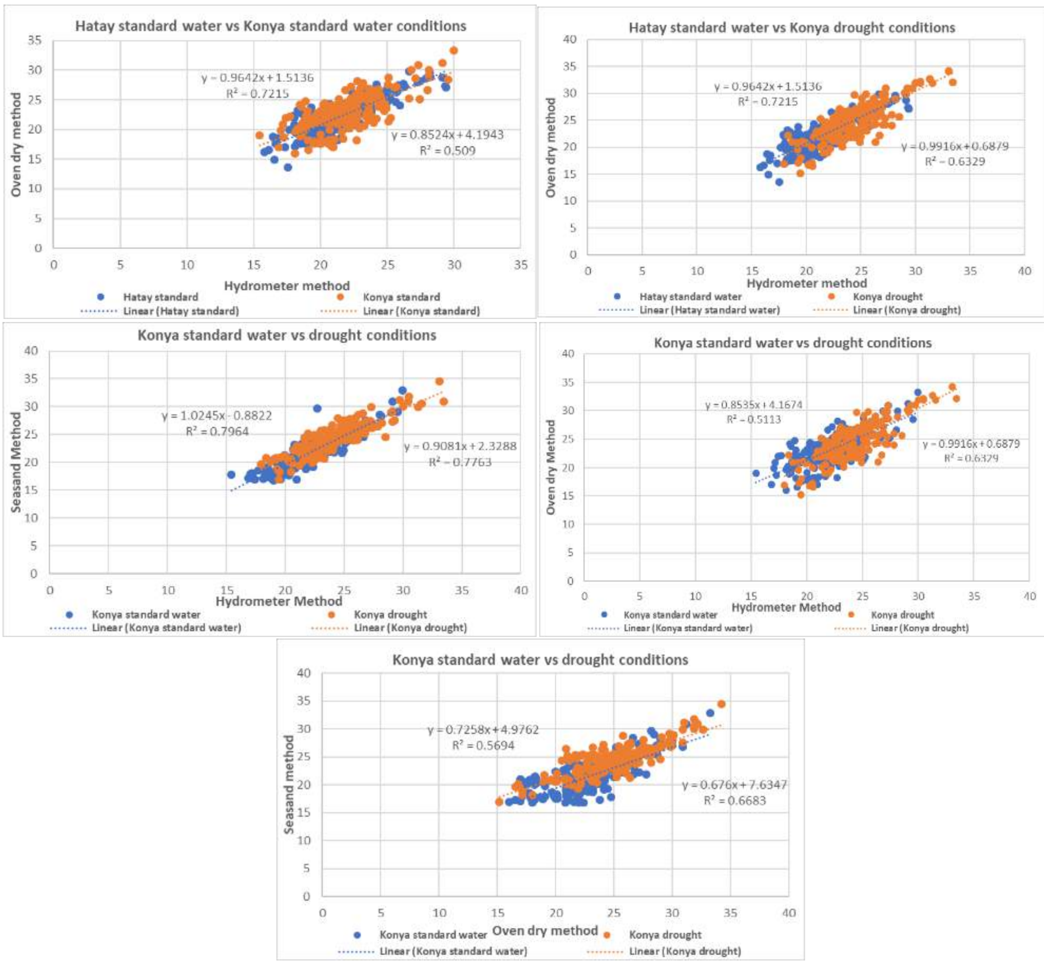

Figure 3. Regression analysis of three different methods for the measurement of tuber dry matter content under three environmental conditions.

Comparison of methods in multi-environments by stability statistics

AMMI (Additive Main effects and Multiplicative Interaction) analysis

Analysis of variance for GEI (genotype by environment interaction) for the variable TDM tested across three environments is depicted in Table 5. The large mean square value of environment showed that the environments were diverse, with large differences among environmental means causing most of the variation in TDM. The significant GEI is an indication that substantial differences were present in genotypic response across the environments. Since, treatments were significant, methods showed differential response within the tested environments. Mean values of TDM vary remarkably from 15.19% to 34.50% in three tested environments and methods, with CV ranging from 10.80% to 13.10% (Table 2 & 3)**.** AMMI biplot showed visual interpretation of interrelationship among genotypes and environments. Mean TDM is plotted against IPC1 (Interactive principal component) as shown in Figure 4. The displacement along abscissa describes the additive (main) effects, while interactive effects can be explained by displacements along the ordinate. If a genotype or an environment has IPC1 score of nearly zero, it has small interaction effects and considered as stable. All three environments were diverse. Interestingly, Konya standard water conditions

(KN18) would be considered as most stable environment. It had positive IPC1 score close to zero, indicating small interaction effects and hence most suitable environment for all genotypes. Abscissa (IPC1) and ordinate (mean TDM) lines bisect each other at the point of intersection. Genotypes which clusters near IPC1 score of zero at the point of intersection, indicates that they were less influenced by the environment. Moreover, they also exhibit an optimum stable TDM content desired by the breeders as well as by the processing industry.

Table 5. Analysis of variance for tuber dry matter content of 189 potato genotypes tested across three environments.

Source	df	SS	MS
Total	1511	15703.78	10.39
TRT	566	13755.76	24.30**
GEN	188	9111.79	48.47**
ENV	2	1882.79	941.40**
GxE	376	2761.18	7.34**
IPC1	189	1878.21	9.94**
Residual	187	882.97	4.72**
Error	945	1948.02	2.06

**significant at p<0.01

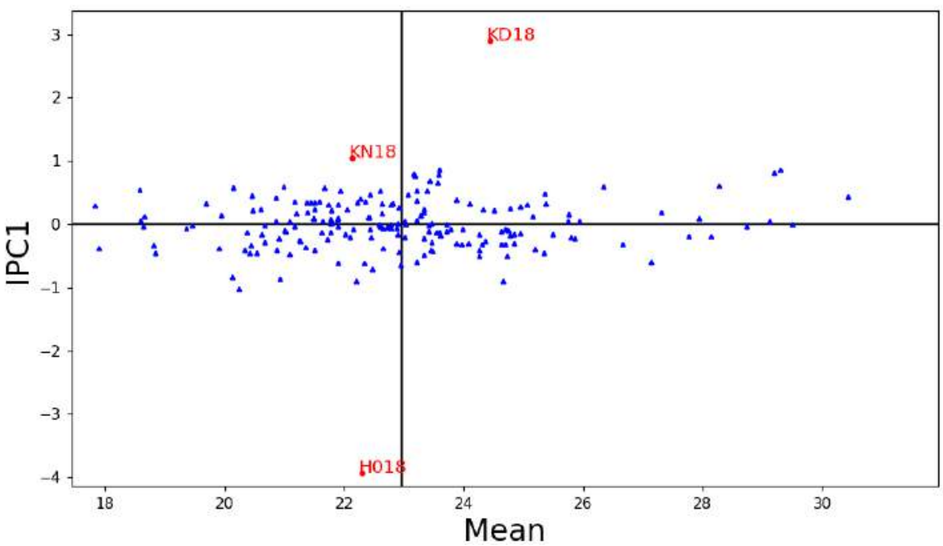

Figure 4. AMMI biplot for TDM mean (%) of 189 potato genotypes (blue dots) and three environments (H018, KN18, KD18) plotted against IPC1 (Interactive principal component)
H018=Hatay-2018; KN18=Konya standard water conditions-2018; KD18=Konya drought conditions-2018

Stability analysis

The adaptation response of large number of genotypes to changing environments can be explained by plotting stability parametric models against mean TDM. Finlay and Wilkinson (1963) and Eberhart and Russell's (1966) proposed stability models such as regression coefficient (*bi*) and deviations from regression (S^2_{di}). TDM determination methods can be compared in terms of stability response of genotypes under various environments to dissect the efficacy of each method. Figures (5 & 6) illustrates two-dimensional scatter plot of each method, by plotting stability indices (*bi* and S^2_{di}) against mean TDM for 189 potato genotypes tested across three environments. Figure (5a) represents a generalized interpretation version of adaptability which can be applied to Figures (5b, c, d). Each point on scatter diagram represents a single genotype and position of the point indicates its adaptability status. Genotypes characterized by *bi* values approximating 1.0 (not significantly different from unity at p<0.05) coupled with S^2_{di} of zero indicates an average stability. An association of *bi* with high mean TDM showed general adaptability to all environments (represented by circle in Figure 5a) as compared to poor adaptability with low mean TDM values. However, mean TDM values greater than 25% were considered as inadmissible limits (Figure 5a). Genotypes characterized by *bi* > 1 showed higher sensitivity to environmental change (i.e., small environmental variation produce large changes), thus specifically adapted to favourable environments. Contrarily, *bi* < 1 refers to a measure of greater resistance to environmental change, thereby specifically adapted to unfavourable environments.

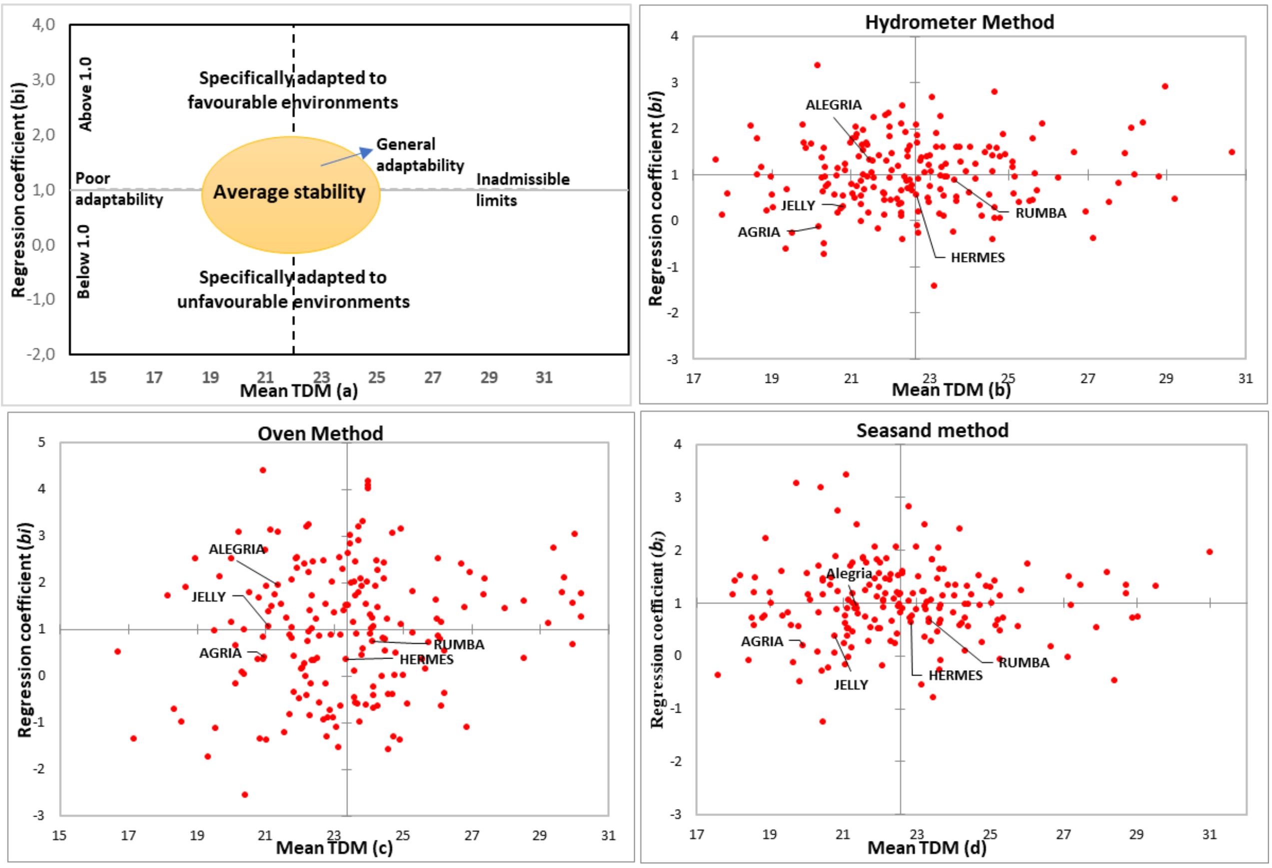

Figure 5a) Generalized interpretation of graph plotted between regression coefficient (*bi*) and mean TDM; **(b,c,d)** Relationship of genotype adaptation (regression coefficient '*bi*') and mean TDM of 189 potato genotypes by various dry matter content determination methods in three diverse environments.

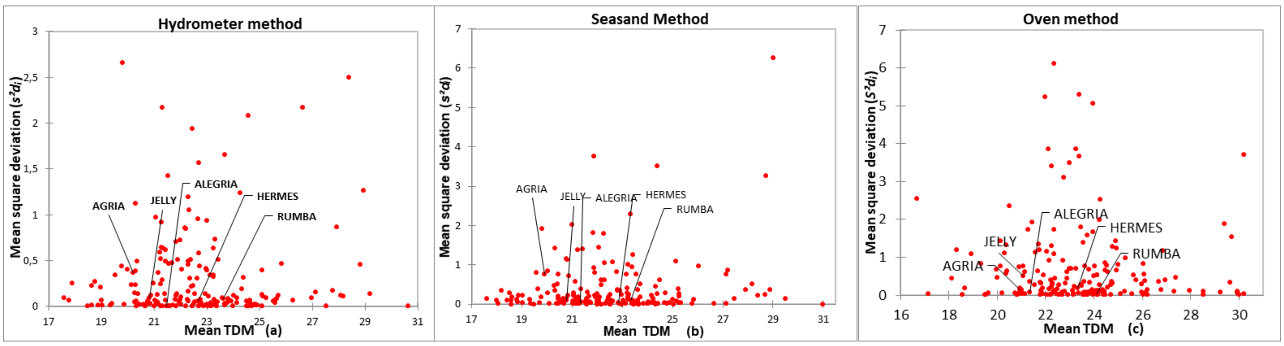

Figure 6a, b, c) Relationship of genotype adaptation (mean square deviation 'S^2_{di}') and mean TDM of 189 potato genotypes by various dry matter content determination methods in three diverse environments (zero indicates average stability).

The quality of processed tuber products (French fries and crisp) is mainly dependent upon ideal range of TDM i.e., between 20% to 25% (McGregor, 2007). Based on this information, Table 6 revealed an optimum mean TDM with respective values of the stability parameters (*bi* and $S^2_{d_i}$) for the 15 most stable genotypes along with 5 check cultivars tested across three environments with three methods. A genotype was considered as stable, when $S^2_{d_i}$ values were lower than the mean, with zero as measure of average stability. The mean values of $S^2_{d_i}$ for hydrometer, seasand and oven methods were 0.30, 0.39 and 0.68, respectively. An average stability was observed with three methods, in all check cultivars except Agria, when $S^2_{d_i}$ was considered as stability parameter. Oven method showed Agria as stable cultivar ($S^2_{d_i}$=0.14) while remaining two methods render it unstable. Deviation from regression was observed to be 0.37 and 0.75 (higher than mean) in hydrometer and seasand methods (Table 6 & Figure 6). Oven method recorded higher $S^2_{d_i}$ values in lines DT12068.21, DT13026.10 and 133-112-11 declaring them unstable, while same lines were tagged as most stable lines by hydrometer and seasand methods. The latter two methods were found to provide similar results while discrepancy had been observed with former method.

Table 6. Optimum means of tuber dry matter content with respective values of the stability parameters (*bi* and S^2d_i) for the 15 most stable genotypes along with 5 check cultivars tested across three environments with three methods.

	Hydrometer method			Seasand method			Oven method		
Genotypes	mean	*bi*[a]	S^2d_i[b]	mean	*bi*	S^2d_i	mean	*bi*	S^2d_i
Agria	20.19	-0.13	0.37	19.90	0.20	0.75	20.96	0.41	**0.14**
Alegria	21.47	**1.29**	**0.00**	21.33	**0.96**	**0.04**	21.36	1.96	**0.07**
Hermes	22.67	**0.78**	**0.06**	22.84	**0.77**	**0.02**	23.34	0.35	**0.17**
Jelly	20.81	0.31	**0.09**	20.77	0.37	**0.10**	21.07	**1.06**	**0.51**
Rumba	23.61	**0.89**	**0.09**	23.33	**0.79**	**0.09**	24.11	**0.73**	**0.04**
Russet burbank	21.58	**0.93**	**0.00**	21.94	**0.71**	**0.17**	22.23	**0.73**	**0.40**
Van Gogh	22.76	**1.29**	**0.07**	22.39	**1.07**	**0.04**	23.57	2.02	**0.06**
Inara	21.58	**0.72**	**0.00**	21.37	**0.89**	**0.05**	22.36	**1.01**	**0.11**
Pomqueen	23.02	**1.08**	**0.00**	22.17	**1.84**	**0.39**	23.18	-0.65	**0.02**
Baltic cream	24.60	**1.08**	**0.02**	24.31	**0.96**	**0.03**	24.13	**1.06**	**0.00**
Bonus	23.40	**1.24**	**0.05**	22.49	**0.94**	**0.01**	24.12	**1.24**	**0.52**
43-118-11	21.56	**1.29**	**0.00**	21.14	**1.06**	**0.01**	21.91	2.53	**0.52**
Lady Olympia	22.40	**0.87**	**0.22**	22.51	**0.98**	**0.23**	22.18	3.19	**0.01**
DT11007.01	23.93	**1.07**	**0.06**	23.28	**1.02**	**0.25**	23.25	2.30	3.85
DT12068.21	20.65	**0.97**	**0.00**	21.26	**0.99**	**0.09**	21.27	1.74	1.73
DT13026.10	22.37	**0.96**	**0.30**	22.09	**0.92**	**0.18**	22.57	**0.86**	**0.00**
DT14030.11	23.30	**1.16**	**0.01**	22.55	**0.81**	**0.01**	24.25	2.27	**0.26**
DT14088.03	20.66	**1.15**	**0.00**	21.53	**1.86**	**0.06**	21.90	2.30	**0.04**
102-102-11	20.37	**0.74**	**0.13**	20.10	**1.05**	**0.01**	21.77	**1.03**	**0.00**
133-112-11	22.88	**1.04**	**0.00**	23.24	**0.88**	**0.13**	22.07	0.16	1.16

[a]printed values in bold are not significantly different from unity at $p<0.05$; genotypes with values in bold are considered stable; [b]printed values in bold are lower than the mean and considered stable. Bold integers have general adaptability to all environments.

Regression coefficient (*bi*) values of check cultivars (Alegria and Hermes) were not significantly different from unity (1.0), in hydrometer and seasand methods, which depicts their general adaptability to all environments. Oven method, however, showed Alegria as precisely adapted to favourable environments (*bi*=1.96, significantly different from unity), while Hermes to unfavourable environments (*bi*=0.35). Same method provides contradictory report in case of cultivar Jelly, as *bi*=1.06 was not significantly different from unity, in contrast to unity significance obtained in hydrometer (*bi*=0.31) and seasand (*bi*=0.37) methods. In terms of adaptability/stability, latter two methods describe Jelly as being specifically adapted to unfavourable environment, while the former (oven method) interprets its general adaptability to all environments. Rumba exhibits general adaptability in all three methods. Interestingly, Agria was designated as precisely adapted to unfavourable environments by all three methods. Genotypes and lines such as Van Gogh, Lady Olympia, Pomqueen, 43-118-11, DT11007.01, DT12068.21, DT14030.11, DT14088.03 and 133-112-11 showed *bi* values significantly different from unity (i.e., varied stability/adaptability), in oven method, while all of the same were found to be most stable (i.e., general adaptability) in hydrometer and seasand methods (*bi* approximating to 1.0; $p<0.05$). Deviated values of stability parameters in oven method showed the superiority and accuracy of hydrometer and seasand methods.

DISCUSSION

Tuber dry matter content determines the sensory perceived characteristics of potato (van Dijk et al., 2002). This is the first comprehensive study to demonstrate a comparison among standard TDM determination methods in multi-environment field trials. Practibility and reliability of methods were analysed using diverse 189 potato genotypes, with TDM range of 15.19% to 34.50%. Deviated results were observed with oven-dry method, while comparable findings were obtained with hydrometer and seasand methods. Hydrometer worked on the principle of under-water weight measurement (UWW). Kumar et al. (2005) noticed that 85% variance in TDM as response variable, was explained by regression model, using UWW/hydrometer as independent variable. A close relationship (R^2=0.94) was recorded between UWW and dry matter content in tubers (Haase, 2003). Moisture-drying on quartz seasand and oven-dry methods have been utilized solely to analyse the dry matter content of potatoes (AACC, 1993a; Haase, 2003, 2011; Caliskan et al., 2004; Bonierbale, 2007; Mebratie and Desta, 2018). Haase (2003, 2011) used moisture drying on quartz seasand (AACC, 1993a, 1993b) as reference method for NIRS estimating calibration equation to measure TDM. Calibration and validation models showed R^2 =0.99, with seasand method (as reference method), disclosing the reliability of this method. Our findings were comparable to the studies mentioned earlier. Interpretation of regression and correlation results revealed a strong relationship between seasand and hydrometer methods in contrast to oven-dry method. The former two methods thus can be used interchangeably.

Seasand is an accurate, reliable, destructive method but offers some limitations in terms of laborious and time consuming. Alternatively, hydrometer is an automated, non-destructive, cheap and rapid method to calculate TDM of large number of tuber samples. It has wide applicability and practibility in laboratory as well as under field conditions for large number of samples (n). Nevertheless, it requires approximately 2500 g of clean raw tubers with minimum of 4-5 replications per sample. It can also estimate the specific gravity of tubers, simultaneously. Precision in dry weight measurements is inevitable for an estimation of water loss in tuber samples meant for dry matter content determination. Evaporative loss of water during measurement of TDM by oven-dry method might be responsible for its less precision. It can be overcome by putting the samples in desiccator and instant measurement of its weight after drying. Vacuum or freeze drying can be used alternatively. The current study thus allows the potato researcher/food analyst at industry to choose, either destructive (moisture-drying on quartz seasand) and/or non-destructive method (potato hydrometer) of TDM measurement. These methods gave stable results over range of environmental conditions.

AMMI analysis validates the presence of GEI indicating that genotypes respond differently in tested environments. Significant differences were present among test and check genotypes included in the study. Mebratie and Desta (2018) tested 105 potato genotypes and found significant variation among control, tests and test vs control genotypes for TDM. Konya standard water regime may be considered ideal for testing TDM of large number of genotypes. Our results were comparable to the findings of Rak et al. (2013). Drought conditions showed high dry matter content as compared to the standard water conditions in Hatay and Konya. Reports suggest that water deficit conditions reduce the tuber water contents, consequently tuber dry matter content increases (Kumar et al., 2007; Sharma et al., 2011). High temperatures reduce the starch contents in tubers. Since, starch and TDM can be used synonymously, high temperature thus decreases the tuber dry matter content (Van Eck, 2007). The decrease in average TDM under Konya standard water conditions compared to Hatay standard water circumstances might be due to relatively high temperature in Konya. AMMI analysis had been used extensively in yield stability studies, indicating most stable high yielding genotypes suitable to specific environments (Hassanpanah, 2010; Lenartowicz et al., 2019). The applicability of this analysis is debatable in current study to identify GEI interactions for huge germplasm collections. Further stability statistical analysis might be helpful to unveil the stable GEI interactions.

Several statistical methods have been proposed for interpretation of GEI (Flores et al., 1998). Parametric stability methods like regression coefficient (*bi*; Finlay and Wilkinson, 1963) and variance of deviations from the regression (S^2_{di}; Eberhart and Russell, 1966) have been used primarily to assess the stability of genotype by associating an observed genotypic response (TDM; *in our case*) to environmental conditions (Pour-Aboughadareh et al., 2019). Reliability of methods can also be judged by stability statistics. Deviation in the stability parametric indices (*bi* and $S^2_{d_i}$) were found in oven method, while seasand and hydrometer indicated similar results, for the same genotypes within each tested environment. Stability parametric analysis disclosed candidate genotypes, depicting optimum stable TDM across the tested environments with three methods. These genotypes can be recommended as a useful genetic resource for breeding of processing cultivars, suitable to Mediterranean and Continental climatic conditions. Genotypes that maintain optimum mean TDM between 20% to 25% in varying environmental conditions are desirable for potato processing industry. Rak et al. (2013) identified desirable lines to extended cold conditions through stability analysis. Same stability parameters were discussed by Akcura et al. (2006) and Mohamed and Ali (2015). Overall, when making selection for optimum TDM, genotypes with too low and too high, mean TDM were eliminated regardless of their *bi* and S^2_{di} values equals to 1 and zero, respectively.

CONCLUSION

The current study concluded the comparative efficacy of both seasand and hydrometer methods in contrast to oven-dry method for the measurement of TDM. The seasand is an accurate, destructive method but offers some limitations in terms of laborious and time consuming. Alternatively, hydrometer is an automated, non-destructive, cheap and speedy method to calculate TDM of large number of tuber samples. Nevertheless, it requires approximately 2500 g of clean raw tubers with minimum of 4-5 replications per sample. A strong correlation and high goodness of fit was observed between seasand and hydrometer methods. The study also reinforce that environmental conditions have significant effect on TDM, and potato genotypes respond differently to environments. Konya standard water conditions prove to be the best among the three environments, for obtaining optimum TDM with less environmental influence. Stability analysis revealed stable genotype clusters among the set of treatments. Certain genotypes were selected and docketed into stable category. These candidate genotypes would be exploited for further molecular studies and serve as a useful resource for breeding of processing cultivars.

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AUTHORS' CONTRIBUTION

All authors contributed equally and had read the manuscript.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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