Evaluating the Element Contents of Durum Wheat Landraces Pure Lines in Çanakkale Conditions

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Received: 25.10.2019 Revised in Received: 07.02.2020 Accepted: 10.02.2020

Abstract
Wheat landraces are often utilized in breeding programs for their potential to improve the grain quality of new varieties. Our goal is to evaluate thousand kernel weights (TKW), percentages of the yellowberry kernels (PYK), B, Ca, Cu, Fe, K, Mg, Mn, Na, Ni, P, S and Zn contents of 25 landraces derived durum wheat pure lines collected from the fauna of Turkey to identify promising candidates. Field trials were conducted in Çanakkale in 2015-2016 and 2016-2017 growing seasons and element contents of pure lines were determined by using ICP-OES. Differences between durum wheat landraces were found statistically significant by all traits (p<0.01). Correlation analysis demonstrated that Ca, Cu and Mg contents of pure lines were positively correlated to each other. Results suggested a valuable variability among durum wheat genotypes in terms of their element contents. Promising candidates were selected for future breeding programs.

Keywords: Durum wheat, element, Çanakkale, biofortification, Landraces

Çanakkale Koşullarında Yerel Makarnalık Buğday Hatlarının Çeşitli Element İçeriklerinin Değerlendirilmesi

Özet
Buğday islahında tane kalitesinin geliştirilmesi amacıyla yerel buğdaylardan yaygın olarak yararlanılmaktadır. Bu çalışmada Türkiye faunasından toplanmış yerel makarnalık buğdaylardan elde edilen 25 adet yerel hat arasında yapılan potansiyel hatları belirlemek amacıyla bin tan ağırlığı (BTA), dönümlü tane oranı (DTO) ile B, Ca, Cu, Fe, K, Mg, Mn, Na, Ni, P, S ve Zn içerikleri incelenmiştir. Araştırma Çanakkale’de 2015-2016 ve 2016-2017 yetiştirme mevsimlerinde yürütülmüş, parsellerden elde edilen tane örneklerinin element içerikleri ICP-OES yöntemi ile belirlenmiştir. İncelenen tüm özellikler bakımından makarnalık buğday hatları arasında gözlemlenen farklıklar istatistiksel olarak önemli bulunmuştur (p<0.01). Korelasyon analizi sonucunda hatların Ca, Cu ve Mg içeriklerinin birbirleri ile olumu ve önemli bir ilişki içerisinde bulundukları belirlenmiştir. Araştırmada bulguların yola çıkarak makarnalık buğday yerel hatlarının element içerikleri bakımından dikkate değer bir çeşitlilik gösterdikleri sonucuna ulaşılmıştır. Belirli elementler bakımından umitverici hatlar seçilmişdir.

Anahtar Kelimeler: Makarnalık buğday, element, Çanakkale, biyofortifikasyon, yerel çeşitler

Introduction
Obtaining new genotypes with the prospect of higher performance and quality is a constant challenge in plant breeding. To this end, breeders and agronomists often study landraces and distant relatives of wheat with hopes to discover useful genotypes to associate in breeding programs. Due to its exceptional
In addition of their earlier use as breeding materials to improve grain yield disease and resistances in wheat, landraces derived pure lines are reported to have a particular potential for the enhancement of grain quality when compared to the cultivars (Gökgöl, 1939; Akçura, 2011; Nazco et al., 2012; Hocaoğlu and Akçura, 2014). A possible explanation for this phenomenon is “the bottleneck effect”, which stands for a decrease of diversity among current breeding materials caused by the constant pressure of selecting for high-yielding genotypes. Continuous selection for grain yield causes a restriction in genotypic variability which resembles a bottleneck: genotypes that don’t come forward by their high yields but may excel at different attributes are eliminated during the selection process. Losing genotypic variation limits the success of later breeding programs particularly by traits other than grain yield, such as grain quality and mineral content (Reif et al., 2005). Researches comparing wheat landraces to varieties often found that landraces populations or landrace derived plant materials had higher genetic diversity (Figliuolo et al., 2007) and higher contents of some microelements and protein in their grain (Konvalina et al., 2008; Zhao et al., 2009; Hocaoğlu and Akçura, 2014). Increasing the microelement content of wheat would lead to a significant contribution to human nutrition, because even though fruits and vegetables are considered as the essential sources of minerals in human diet (Martinez-Ballesta et al., 2010), mineral malnutrition is an important health problem today, which is often linked with carbohydrate-rich unbalanced diets. This is especially common in the developing countries where severe health problems due to this type of malnutrition is caused by the lack of diversity of food substances (Welch, 2002). Although a permanent solution for this problem calls for a more comprehensive effort including social, economic and legal aspects of the situation, increasing mineral contents of staple foods may have an immediate effect and provide to be a short-term solution (White and Broadley, 2005). Mineral fertilization, increasing bioavailability of nutrients or breeding new varieties with increased capacity of mineral accumulation towards their edible organs are considered as valid solutions to reduce dietary malnutrition (White and Broadley, 2005). Therefore, monitoring landraces for quality related traits allows the identification of valuable germplasm to complement nutritional aspects of breeding programs.

This research aims to compare 25 landraces derived pure lines by their B, Ca, Cu, Fe, K, Mg, Mn, Na, Ni, P, S and Zn contents. In addition to the element contents and thousand kernel weights (TKW), percentages of yellowberry kernels of pure lines were also investigated to reveal insights about the current condition of growing landraces pure lines Çanakkale conditions. Yellowberry kernels in durum wheat is a physiological disorder where soft yellow stains occur on the grain due to the disruption of vitreous protein matrix by excessive starch accumulation. Therefore, presence of the yellowberry kernels decreases overall vitreousness and by doing so negatively effects the grain quality. Yellowberry kernels can be caused by climatic factors such as high air humidity/precipitation during the seed development or prolonged duration of seed development (Gülec et al., 2010). Therefore, identifying suitable durum wheat varieties for the climate of the growing are is important to reduce the percentages of yellowberry kernels (Pehlivan and ikincikarakaya, 2017).

Materials and Methods
Pedigree information and the registration codes of durum wheat genotypes are given in Table 1. Field trials are designed according to the randomized complete block design with four replications and were conducted in 2015-2016 and 2016-2017 growing seasons in Çanakkale. Plots were arranged to be 0.8 m wide and 2 m long with 4 rows each. Sowing density was 500 seeds m⁻².8 kg da⁻¹ P₂O₅ and 15 kgda⁻¹ N fertilizer applied in total. Total dose of N fertilizer is divided into two doses for a better match with plant growth: first dose (10 kg da⁻¹) is applied during the sowing when the rest is applied by the beginning of stem erection. Weeds were controlled with commercial herbicide containing the active substance of chlorosulphuron.
Table 1. List of landrace-derived durum wheat pure lines

| No | Landrace code and pedigree | Origin |
|----|----------------------------|--------|
| 1  | YÇ-35 (Koca buğday MB-2005-6-7-01) | Konya |
| 2  | YÇ-30 (Bulgurluk MB-2005-28-24) | Konya |
| 3  | YÇ-36 (Koca buğday MB-2005-43-11) | Konya |
| 4  | YÇ-47 (İr buğday MB-2005-72-03) | Konya |
| 5  | YÇ-33 (An buğday MB-2005-12-16) | Konya |
| 6  | YÇ-29 (Koca buğday MB-2008-17-16) | Konya |
| 7  | YÇ-37 (Koca buğday MB-2008-01-20) | Konya |
| 8  | YÇ-28 (Koca buğday MB-2008-06-16) | Konya |
| 9  | YÇ-41 (Koca buğday MB-2008-05-23) | Konya |
| 10 | YÇ-1 (Bulgurluk MB-2009-13-08) | Eskişehir |
| 11 | YÇ-2 (Bulgurluk MB-2009-06-04) | Eskişehir |
| 12 | YÇ-3 (Bulgurluk MB-2009-03-19) | Eskişehir |
| 13 | YÇ-4 (Bulgurluk MB-2009-08-21) | Eskişehir |
| 14 | YÇ-5 (Bolavadin MB-2006-12-03) | Eskişehir |
| 15 | YÇ-7 (San baş MB-2006-09-09) | Eskişehir |
| 16 | YÇ-8 (İr buğday MB-2006-05-09) | Eskişehir |
| 17 | YÇ-9 (Koca buğday MB-2006-08-24) | Eskişehir |
| 18 | YÇ-10 (Bulgurluk MB-2006-06-11) | Eskişehir |
| 19 | YÇ-12 (Bolavadin MB-2010-20-04) | Eskişehir |
| 20 | YÇ-13 (San buğday MB-2010-17-16) | Eskişehir |
| 21 | YÇ-15 (Ak buğday MB-2010-11-22) | Eskişehir |
| 22 | YÇ-16 (Koca buğday MB-2010-10-14) | Eskişehir |
| 23 | DMB-63 (Bolavadin MB-2010-01-01) | Ankara |
| 24 | Yabanı-67 (Buğday MB-2012-03-07) | Kayseri |
| 25 | YÇ-44 (San buğday MB-2012-05-15) | Konya |

Harvested plants were threshed with a stationary thresher. Seed counts and measurements for the assessments of the thousand kernel weights and percentages of yellowberry kernels were made in the laboratory. A set of grain samples were ground. B, Ca, Cu, Fe, K, Mg, Mn, Na, Ni, P, S and Zn contents of 54 durum wheat genotypes are determined by ICP-OES (inductively coupled plasma - optical emission spectrometry). Sample preparations and ICP-OES readings are held in accordance with Akçura et al. (2019) and Mertens (2005).

Results are evaluated with ANOVA and the correlation analysis. Averages of both experiment years are represented as a heatmap for an easier evaluation (Table 3).

Results and Discussion

Combined ANOVA of two years results showed that genotype effects were significant for all traits at p<0.01 level (Table 2). Least significant difference (LSD) values, mean, minimum, and maximum of each trait are presented in the bottom of the heatmap given in Table 2.

Table 2. Variance analysis results of landraces genotypes

| Parameters | Sources of variation |
|------------|----------------------|
|            | DF | Year | Rep | Gn | Year*Gn | Error | Total | CV | R² |
|            |    |      |     |    |         |       |       |    |    |
|            | 1  | 24   |     | 24 | 96      | 149   |        |    |    |
| B          |    | 110.36 | 9.22 | 77.59** | 11.50** | 1.97 | 16.61 | 17.61 | 0.92 |
| Ca         | 6336.55 | 1703.9 | 49222.40** | 25229.14** | 483.78 | 12392.16 | 5.34 | 0.97 |
| Cu         |    | 9.78  | 0.62 | 10.10** | 10.19** | 0.26 | 3.52 | 8.69 | 0.95 |
| Fe         | 389.4 | 27.77 | 217.30** | 191.93** | 2.49 | 70.88 | 3.25 | 0.98 |
| K          | 9407317 | 164851 | 1443406** | 900601** | 12315 | 453055 | 2.87 | 0.98 |
| Mg         | 2329.40 | 8070.74 | 101904** | 16181.02** | 1250.59 | 20058.56 | 4.85 | 0.96 |
| Mn         |    | 13.56 | 46.12 | 201.38** | 143.30** | 3.14 | 58.87 | 6.64 | 0.97 |
| Na         | 1022.19 | 216.35 | 14155.27** | 7677.66** | 108.89 | 3599.54 | 6.67 | 0.98 |
| Ni         |    | 4.41  | 0.63 | 7.56** | 1.38** | 0.18 | 1.6 | 23 | 0.93 |
| P          | 593802 | 138812 | 971332** | 818263** | 17318 | 307126 | 3.57 | 0.96 |
| S          | 1188 | 99946 | 319982** | 220133** | 6554 | 93912 | 4.57 | 0.96 |
| Zn         | 884 | 15 | 148** | 186** | 3 | 62 | 3.73 | 0.97 |
| TKW        | 3852 | 263 | 89** | 60** | 5 | 60 | 5.63 | 0.95 |
| PYK        | 10.94 | 3.93 | 13.72** | 18.15** | 2.01 | 6.61 | 22 | 0.80 |

All field applications are made by hand. **: P<0.01, DF: Degree of Freedom, Gn: Genotype, CV: Coefficient of variation (%), R²: R squared, B: Boron, Ca: Calcium, Cu: Copper, Fe: Iron, K: Potassium, Mg: Magnesium, Mn: Manganese, Na: Sodium, Ni: Nickel, P: Phosphorus, S: Sulfur, Zn: Zinc, TKW: Thosand kernel weight (g), PYK: Percentage of yellowberry kernels (%).
In Table 3, genotype performances can be compared against each other by using the cell color as an indicator: darker shade of green represent the preferability of a genotype which is associated with the higher microelement contents, higher TKW and lower percentages of yellowberry kernels. According to the heatmap, almost every durum wheat pure line had a unique element composition where selecting for a perfect genotype were not possible. Thus, choosing several genotypes as possible for a perfect genotype were not possible. Thus, unique element composition where selecting almost every durum wheat pure line had a yellowberry kernels.

Highest average TKW were obtained from the genotypes 24, 9 and 1, all of which had a PYK (between %5.5 and 5.75) lower than the mean PYK of all genotypes (%6.39, Table 2). However, their element compositions varied greatly. Both genotypes 11 and 2 had reasonably high element compositions when genotype 2 would be preferable in terms of combining high TKW with lower PYK. (Table 3).

PYK averages of durum pure lines were found to be promising. According to the rate card declared from the Turkish Grain Board, 27% PYK is the upper limit for Group I durum averages of Na and Ni contents. Moreover, genotype 13 had the highest K and Ca contents when genotypes 14, 7 and 8 were prominent by B, Fe and Zn contents, respectively.

In Table 3, genotype number, TKW: Thosand kernel weight (g), PYK: Percentage of yellowberry kernels (%). Since durum wheat landraces genotypes with the higher element contents and lower PYK are considered to be more promising, better candidates for any given trait are indicated with the darker shades of green when darker shades of red indicates the opposite.
wheat (Anonymous, 2019), meaning that the higher percentages of yellowberry kernels than this ratio causes financial loses for the farmers. Our results suggest that PYK of landrace derived pure lines differed between 2.75% - 9% (Table 3). Since genotype averages falls under 27% we conclude that durum wheat cultivation in Çanakkale province may be feasible in terms of meeting the quality requirements of the market.

Results of the correlation analysis revealed several significant relationships between various element contents (Table 4). Most significant relationships were observed between P and K (0.58) and Mg and S (0.55). Mg, Ca and Cu were also positively correlated with one other with varying correlation coefficients between 0.42 and 0.45. These relationships are more visible in the colored representation of the correlation table (Figure 1), where two bulks of positive and significant relationships can be observed. First bulk included Ca, Cu and Mg when a second bulk can be observed near the first, including Mg, S, P and K (Figure 1). Similar positive correlations among Mg, Ca and Cu contents were reported before on a set of old and modern durum wheat varieties (Ficco et al., 2009). Hakkı et al. (2014) confirmed positive correlations between

**Table 4. Correlation coefficients between investigated parameters of pure lines**

|       | B  | Ca | Cu | Fe  | K   | Mg  | Mn  | Na  | Ni  | P   | S   | Zn  | TKW  |
|-------|----|----|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|
| Ca    |    | -0.15 |   |     |     |     |     |     |     |     |     |     |      |
| Cu    | 0.04 |     | 0.22 |     |     |     |     |     |     |     |     |     |      |
| Fe    | 0.10 | -0.04 | -0.03 |     |     |     |     |     |     |     |     |     |      |
| K     | 0.00 | 0.07 | 0.12 | 0.22 |     |     |     |     |     |     |     |     |      |
| Mg    | 0.10 | 0.42** | 0.45** | -0.06 | 0.42** |     |     |     |     |     |     |     |      |
| Mn    | 0.23 | 0.01 | -0.23 | -0.04 | -0.16 | 0.02 |     |     |     |     |     |     |      |
| Na    | 0.02 | -0.02 | 0.17 | -0.18 | 0.13 | -0.16 | -0.05 |     |     |     |     |     |      |
| Ni    | 0.20 | 0.34** | 0.03 | 0.14 | 0.03 | 0.10 | -0.06 | 0.09 |     |     |     |     |      |
| P     | -0.13 | -0.01 | 0.24 | 0.28* | 0.58** | 0.45** | -0.01 | -0.25 | -0.20 |     |     |     |      |
| S     | -0.19 | 0.28* | 0.28* | -0.21 | 0.20 | 0.55** | -0.19 | -0.12 | 0.22 | 0.30 |     |     |      |
| Zn    | -0.01 | -0.01 | -0.07 | 0.27* | 0.4** | 0.09 | 0.09 | 0.38** | -0.08 | 0.41** | -0.18 |     |      |
| TKW   | -0.07 | 0.04 | 0.04 | 0.04 | -0.27 | -0.02 | -0.01 | -0.11 | 0.14 | 0.04 | 0.23 | -0.16 |      |
| PYK   | -0.10 | 0.02 | -0.23 | 0.10 | -0.19 | -0.36 | 0.04 | -0.05 | 0.14 | 0.11 | -0.21 | 0.43** | -0.04 |

* significant at p<0.05, ** significant at p<0.01.
Mg, P and S but reported non-significant correlations among Mg, Ca and Cu contents of several Turkish durum wheat genotypes. Correlation analysis did not reveal any significant relationships between TKW and other traits. Similarly, non-significant negative associations can be seen between many elements with PYK except for Zn, which were found to be positively and significantly correlated to PYK (0.43). TKW and PYK were negatively correlated but this relation was not statistically significant (Table 4).

In conclusion, given the importance of durum wheat products in Turkey, biofortification of durum grain by element contents would contribute to our nutrition. There are many studies underlining this issue, especially by Fe and Zn contents. Reports indicate that human diet often lacks sufficient amounts of Fe and Zn in the developing countries (Welch and Graham 2002). Element contents of crops can be increased through increasing the amount of mineral fertilization but depending on this alone will bring additional costs to the farmers and bring about the risk of pollution in both soil and groundwaters (Xu et al., 2011). Thus, plant breeding is considered as the foremost measure for biofortification which relies to the discovery of new genotypes with higher capability of metabolizing and storing elements (Cakmak et al., 2010). In our study, pure lines 24 and 2 can be recommended for cultivation in Çanakkale ecological conditions when all traits were considered. Additionally, genotypes 2, 7, 8, 11, 13, 14 and 24 were found to be promising candidates to increase element contents of durum wheat. Landrace derived pure lines were confirmed to contain a great variability, proving to be valuable assets to the future quality breeding programs.

Acknowledgements
Authors thank COMU BAP commission for their financial support under the project no: FBA-2018-2608.

References
Anonymous. 2019. Toprak Mahsulleri Ofisi Genel Müdürlüğü 2019 Dönemi Hububat Alım Baremi. (http://www.tmo.gov.tr) (In Turkish. Date of access: 11.06.2019).
Akçura, M. 2011. The relationships of some traits in Turkish winter bread wheat landraces. Turkish Journal of Agriculture and Forestry, 35(2), 115-125.
Akcura, M., Turan, V., Kokten, K., Kaplan., M. 2019. Fatty acid and some micro element compositions of cluster bean (Cyamopsis tetragonoloba) genotype seeds growing under Mediterranean climate. Industrial crops and products, 128: 140-146.
Altıntaş, S., Toklu, F., Kafkas, S., Kilian, B., Brandolini, A., Özkan, H. 2008. Estimating genetic diversity in durum and bread wheat cultivars from Turkey using AFLP and SAMPL markers. Plant Breeding, 127(1), 9-14.
Ateş Sönmezoglu, Ö, Bozmaz, B., Yıldırım, A., Kandemir, N., Aydin, N. 2012. Genetic characterization of Turkish bread wheat landraces based on microsatellite markers and morphological characters. Turkish Journal of Biology, 36(5), 589-597.
Cakmak, I., Pfeiffer, W. H. 2010. Biofortification of Durum Wheat with Zinc and Iron. Cereal Chem. 87(1):10–20.
Ficco, D. B. M., Riefolo, C., Nicastro, G., De Simone, V., Di Gesu, A. M., Beleggia, R., Platani, C., Cattivelli, L., De Vita, P. 2009. Phytate and mineral elements concentration in a collection of Italian durum wheat cultivars. Field Crops Research, 111(3), 235-242.
Figliuolo, G., Mazzeo, M., Greco, I. 2007. Temporal variation of diversity in Italian durum wheat germplasm. Genetic Resources and Crop Evolution, 54(3), 615-626.
Gökgöl, M. 1939. Türkiye Bugdayları Cilt II, Yeşilköy Tohum İlahı Enstitüsü, Yayın No: 14.
Güleç, T. E., Sönmezoglu, Ö. A., Yıldırım, A. 2010. Makarnalik bugdaylarda kalite ve kaliteyi etkileyen faktörler. Gaziosmanpaşa Üniversitesi Ziraat Fakültesi Dergisi, 2010(1), 113-120.
Hakki, E. E., Dograr, N., Pandey, A., Khan, M. K., Hamurcu, M., Kayis, S. A., Gezgin, S, Ölmez, F., Akkaya, M. S. 2014. Molecular and elemental characterization of selected Turkish durum wheat varieties. Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 42(2), 431-439.
Hocaoglu, O., Akcusa, M. 2014. Evaluating yield and yield components of pure lines selected from bread wheat landraces.
comparatively along with registered wheat cultivars in Canakkale ecological conditions. *Türk Tarım ve Doğa Bilimleri Dergisi*, 1(Özel Sayı-2), 1528-1539.

Kabbaj, H., Sall A. T., Al-Abdallat, A., Geleta, M., Amri, A., Filali-Maltouf, A., Belkadi, B., Ortiz, R., Bassi, F. M. 2017. Genetic Diversity within a Global Panel of Durum Wheat (*Triticum durum*) Landraces and Modern Germplasm Reveals the History of Alleles Exchange. *Front Plant Sci*. 2017 doi: 10.3389/fpls.2017.01277.

Karagöz, A., Zencirci, N. 2005. Variation in wheat (*Triticum* spp.) landraces from different altitudes of three regions of Turkey. *Genetic Resources and Crop Evolution*, 52(6), 775-785.

Konvalina, P., Moudrý jr, J., Moudrý, J. 2008. Quality parametres of emmer wheat landraces. *Journal of Central European Agriculture*, 9(3), 539-545.

Martinez-Ballesta, M. C., Dominguez-Perles, R., Moreno, D. A., Muries, B., Alcaraz-Lopez, C., Bastias, E., Garcia-Viguerà, C., Carjaval, M., 2010. Minerals in plant food: effect of agricultural practices and role in human health. A review. *Agronomy for Sustainable Development*, Springer Verlag/EDP Sciences/INRA, 30 (2), 10.1051/agro/2009022.

Mertens, D. 2005. *AOAC Official Method 975.03*. AOAC International Suite, Gaitherburg, MD, USA, pp. 3–4 Chapter 3.

Nazco, R., Villegas, D., Ammar, K., Pena, R. J., Moragues, M., Royo, C. 2012. Can Mediterranean durum wheat landraces contribute to improved grain quality attributes in modern cultivars?. *Euphytica*, 185(1), 1-17.

Pehlivan, A., İkincikarakaya, S. Ü., 2017. Makarnalık buğdayda kalite ıslahı çalışmalar. *Tarla Bitkileri Araştırma Enstitüsü Dergisi*, 26(1), 127-151.

Reif, J. C., Zhang, P., Dreisigacker, S., Warburton, M. L., van Ginkel, M., Hoisington, D., Bohn, D., Melchinger, A. E. 2005. Wheat genetic diversity trends during domestication and breeding. *Theoretical and Applied Genetics*, 110(5), 859-864.

Welch, R. M. 2002. The impact of mineral nutrients in food crops on global human health. *Plant and Soil*, 247(1), 83-90.

Welch, R.M., Graham, R.D., 2002. Breeding crops for enhanced micronutrient content. *"From: Food Security in Nutrient-Stressed Environments: Exploiting Plants’ Genetic Capabilities”* Springer, Netherlands, 267-276.

White, P. J., Broadley, M. R. 2005. Biofortifying crops with essential mineral elements. *Trends in plant science*, 10(12), 586-593.

Xu, Y., An, D., Li, H., Xu, H. 2011. Breeding wheat for enhanced micronutrients. *Canadian Journal of Plant Science*, 91(2), 231-237.

Zhao, F. J., Su, Y. H., Dunham, S. J., Rakszegi, M., Bedo, Z., McGrath, S. P., Shewry, P. R. 2009. Variation in mineral micronutrient concentrations in grain of wheat lines of diverse origin. *Journal of Cereal Science*, 49(2), 290-295.