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Wet-Milling Qualities of Dent Corn (*Zea mays indentata* L.) Hybrids Grown as Main Crop in Adana and Sakarya

Abdulvahit SAYASLAN[1]* Rüveyda EROL MERCAN[2]
Ahmet DUMAN[3] Mehmet Ali SAKİN[4]

[1]Karamanoğlu Mehmetbey University, Faculty of Engineering, Department of Food Engineering, Karaman
[2]Ministry of Food, Agriculture and Livestock, Rize Food Control Laboratory, Rize
[3]Ministry of Food, Agriculture and Livestock, Maize Research Institute, Sakarya
[4]Gaziosmanpaşa University, Faculty of Agriculture, Department of Field Crops, Tokat
*e-mail: sayaslan@kmu.edu.tr

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Abstract: Although dent corn (*Zea mays indentata L.*) production has steadily increased in Turkey, limited research has been conducted on suitability of corn hybrids for starch production, i.e., wet-milling quality. This research was therefore conducted to determine physical properties (thousand-kernel weight, hectoliter weight, hardness and density), chemical compositions (protein, fat, ash and starch contents) and wet-milling quality parameters (steep-water solids, germ, gluten, total fiber, starch yields, etc.) of dent corn hybrids grown as the main crop in Adana and Sakarya. Corn hybrids grown in Adana revealed significant differences in their physical, chemical and wet-milling properties. The hybrids Helen, P 31 P 41, P 31 G 98, P 31 N 27 and P 32 W 86 were found to have superior wet-milling qualities. The hybrids grown in Sakarya also exhibited significant differences in certain physical and chemical parameters, yet they did not differ significantly in starch yield, recovery and purity, inferring their similar wet-milling qualities. Additionally, positive correlations of hectoliter weight with hardness, density and protein content, negative correlations of protein content with starch content, yield and recovery, positive correlation of starch content with starch yield were of noteworthy.

Keywords: Corn, maize, starch, quality, wet-milling, *Zea mays indentata*

Adana ve Sakarya'da Birinci Ürün Olarak Yetiştirilen At Dişi Mısır (*Zea mays indentata* L.) Hibritlerinin Yaş-Öğütme Kaliteleri

Öz: Türkiye'de at dişi mısır (*Zea mays indentata L.*) üretiminin sürekli artışına rağmen, mısır hibritlerinin nişasta sanayine uygunluğu (yaş-öğütme kalitesi) hakkındaki araştırmalar sınırlıdır. Bu araştırma, Adana ve Sakarya'da birinci ürün olarak yetiştirilen mısır hibritlerinin fiziksel özellikleri (bin tane ağırlığı, hektolitre ağırlığı, sertlik ve yoğunluk), kimyasal bileşimleri (protein, yağ, kül ve nişasta) ve yaş öğütme parametrelerini (ıslatma suyuna geçen kuru madde, embriyo, gluten, toplam lif, nişasta verimleri vb.) belirlemek amacıyla yürütülmüştür. Adana'da yetiştirilen mısır hibritleri fiziksel, kimyasal ve yaş öğütme özellikleri bakımından önemli farklılıklar göstermiştir. Helen, P 31 P 41, P 31 G 98, P 31, N 27 ve P 32 W 86 hibritleri, üstün yaş öğütme özelliklerine sahip bulunmuştur. Sakarya'da yetiştirilen mısır hibritleri de bazı fiziksel ve kimyasal özellikler bakımından farklılık göstermiştir; ancak nişasta verimi, randımanı ve saflığı bakımından farksız bulunmuştur. Bu durum yaş öğütme özelliklerinin benzer olduğunu göstermektedir. Ayrıca, hektolitre ağırlığı ile sertlik, yoğunluk ve protein içeriği arasındaki pozitif korelasyonlar, protein içeriği ile nişasta içeriği, verimi ve randımanı arasındaki negatif korelasyonlar, nişasta içeriği ile nişasta verimi arasındaki pozitif korelasyon önem arz etmektedir.

Anahtar kelimeler: Mısır, nişasta, kalite, yaş öğütme, *Zea mays indentata*

1. Introduction

Maize or corn (*Zea mays* L.) is the leading cereal grain in the world with an annual production of about one billion tons in 2014 (FAO, 2016). Corn production in Turkey follows wheat and barley, although it has steadily increased to almost 6 million tons in recent years (FAO, 2016). Among the cultivated corn types, dent corn (*Zea mays indentata* L.) constitutes the major percentage of world production. Adana and Sakarya, having respectively about 30% and 20% shares, are two major corn producing provinces in Turkey. Even though production amounts of corn and corn starch have increased in recent years, research on suitability (wet-milling quality) of corn hybrids grown in Turkey for starch production is rather limited. Apart from this work, one doctoral dissertation that was partially accomplished in our laboratory is available (Özsisli, 2010), in which wet-milling qualities of dent corn hybrids grown as main or second crop were compared.

Wet-milling is defined as aqueous separation process of starch and other valuable components from starch-rich materials (Sayaslan, 2004). Commercially, corn, wheat, potato and tapioca (cassava) are used in wet-milling to produce starch (Sayaslan and Gökmen, 2008). Corn starch constitutes more than 80% world total starch production. Upon wet-milling of corn, five fractions are obtained; namely starch (60-70%), gluten/protein (5-15%), fiber (10-15%), germ (5-10%) and steep-water solids (5-8%) (Watson, 1984; May, 1987; Singh, 1999; Eckhoff, 2004). Assessment of corn wet-milling quality is based mainly on the yield, recovery and purity of starch fraction (Hellevang and Wilcke, 1996; Eckhoff, 2004; Morris, 2004). In Turkey, there are seven large-scale wet-milling plants, all of which process only dent corn for starch production (Sayaslan and Gökmen, 2009). Starch and its derivatives have been mainly used in food industry (Seib, 1994; Maningat and Seib, 1997; Bergthaller, 2004; Sayaslan, 2004); however, their usage has recently increased in bioethanol, bioplastics and other chemical industries (Maningat and Bassi, 2004; Feige, 2007; Sanderson, 2007; Witt, 2007).

Corn wet-milling quality is influenced by the genotype (corn type and hybrid), growing conditions and postharvest treatments such as transportation, drying and storage (Singh, 1999; Eckhoff, 2004). In terms of corn type, dent corn is best suited for wet-milling due to its higher starch content that increases starch yield. Additionally, softer endosperm texture of dent corn facilitates ease of separation, which increases starch recovery (Fox et al., 1992; Hellevang and Wilcke, 1996; Singh, 1999; Eckhoff, 2004). Wet-milling quality of dent corn also differs by hybrid. In this regard; kernel size (thousand-kernel weight) and grain hardness are key variables influencing wet-milling characteristics of hybrids. Larger kernels contain more endosperm and thus higher level of starch, leading to increased starch yield in wet-processing (Fox et al., 1992). On the other hand, harder kernels commonly have higher density and protein content sand lower starch contents, resulting in lower starch recovery (Hellevang and Wilcke, 1996; Eckhoff, 2004. It was reported however that differences in kernel size and hardness, both affected by genotype and environment (Sing, 1999; Rooney and Suhendro, 2001), explained only 40 to 50% of variation in wet-milling qualities of corn hybrids (Jackson, 1996). It is well-known that there are unexplained variations in the wet-milling qualities of corn hybrids with similar physical properties and chemical compositions; it is therefore essential to employ laboratory-scale wet-milling tests to differentiate processing qualities of different corn hybrids grown in diverse environmental conditions. Indeed, in a six-year study conducted in the USA, starch yields of commercially produced dent corn hybrids were found to vary from 50 to 72% (Eckhoff, 2004; Morris, 2004).

Postharvest treatments such as transportation, drying and storage affect wet-milling quality of corn (Hellevang and Wilcke, 1996; Singh et al., 1998a and 1998b; Eckhoff, 2004). Corn kernels exposed to excessive mechanical forces during improper harvest, transportation and drying can cause cracking of kernels, which elevates loss of corn solids during steeping and reduces wet-milling quality (Wang and Eckhoff, 2000; Mbuvi and Eckhoff, 2002). Also, drying of corn over 55ºC for extended period was found to strengthen protein-starch interactions in the endosperm and to intensify rubbery structure of germ, both of which reduced the wet-milling quality of corn (Mistry et al., 2003; Morris, 2004; Eckhoff, 2004).

Given the facts that corn and corn starch productions have been increasing in Turkey and that limited research is available on their wet-milling qualities, the purpose of this study was therefore to investigate the physical properties, chemical compositions and wet-milling qualities of corn hybrids grown as the main crop in Adana and Sakarya, two diverse climatic regions of Turkey.

2. Materials and Methods

2.1. Materials, locations and experimental approach

Dent corn hybrids used in this study (Table 1) were grown as main crop in Adana (Agricultural Research Field of Çukurova University) and Sakarya (Agricultural Research Field of Maize Research Institute) with three replications in 2008 and 2009 growing seasons.

Table 1. Dent corn hybrids grown by location
Çizelge 1. *Lokasyona göre yetiştirilen at dişi mısır hibritleri*

No	Adana		Sakarya	
	Hybrid	Source	Hybrid	Source
1	Arma	Syngenta	ADA 523	ADS Seed
2	Brasco	Syngenta	Cadız	Fito Seed
3	DKC 6022	Monsanto	DKC 6418	Monsanto
4	DKC 6842	Monsanto	DKC 6842	Monsanto
5	Helen	Limagrain	Factor	Syngenta
6	King	May Agro	Helen	Limagrain
7	P 31 G 98	Pioneer	Kermess	KWS Türk
8	P 31 N 27	Pioneer	LG 2712	Anadolu
9	P 31 P 41	Pioneer	OSSK 602	Tareks
10	P 32 W 86	Pioneer	P 31 G 98	Pioneer
11	Progen 1303	Özbuğday	P 32 W 86	Pioneer
12	Progen 1661	Özbuğday	Sancia	Agromar
13	Sele	May Agro	Shemal	May Agro
14	Shemal	May Agro	Tector	Syngenta
15	Tietar	Monsanto	Tietar	Monsanto

Instead of choosing the same genotypes in both locations, the genotypes that were widely cultivated in each location with higher economic value were included in the study. Furthermore, hybrids were chosen from as many seed companies as possible to practically avoid genotypes with similar backgrounds.

Adana is located in the Mediterranean region with an altitude of 33m, while Sakarya in the West Black Sea region with an altitude of 31 m. During the growth seasons of 2008 and 2009, both locations had their typical climate conditions. Mean temperatures of Adana from April to October in 2008 and 2009 growth years were respectively 21.1 and 19.7 ^{0}C, whereas 20.8 and 20.9 ^{0}C in Sakarya during the same period. Total rainfall from April to October for 2008 and 2009 growing seasons were respectively 58.7 and 82.9 mm in Adana and 295.5 and 287.4 mm in Sakarya (MGM, 2016). Both locations had clay-loam soil characteristics with pH ranging from 7.49 to 7.89 and organic matter from 0.91 to 1.87%.

Dent corns hybrids were planted with three replications in each location for two years by the randomized complete block design. Each plot was consisted of 39.2 m^2 (7.0 m x 5.6 m) of area containing eight rows. Depending on soil analyses of the locations, nitrogen and phosphorus fertilizations, based respectively on 20 kg^{-da} and 7 kg^{-da}, were applied. Conventional tilling, husbandry, irrigation, plant protection and related technical works were carried out by Kırtok (1998).

2.2. Physical properties

Test (hectoliter) weights and thousand-kernel weights of corn hybrids were measured as described by Elgün et al. (2002). True density and hardness values of the hybrids were respectively determined using gas pycnometer (AccuPyc II 1340, Micromeritics, USA) and Stenvert hardness mill (Micro hammer mill, Glen Mills, USA) as described by Zehret al. (1995) and Singh et al. (1997).

2.3. Chemical compositions

Chemical compositions of corn grains were determined by the standard methods of the American Association of Cereal Chemists International (AACCI, 2000). Corn samples were ground using a laboratory mill (Polymix PX-MFC, Kinematica AG, Switzerland) to pass through 1.0 mm screen. Moisture contents of the samples were determined through oven-drying at 103°C until reaching constant weight by the standard method 44-15A (AACCI, 2000). Protein contents of the corns and isolated starches were measured through Dumas combustion by the standard method 46-30 (AACCI, 2000). Fat contents of corn samples were quantified through Soxtec extraction by the standard method 30-25 (AACCI, 2000). Ash contents were determined through ashing in furnace at 550-590 °C until reaching constant weight by the standard method 08-01 (AACCI, 2000). Starch contents of corn hybrids were measured using enzymatic kits as described in the standard method 76-13 (AACCI, 2000).

2.4. Wet-milling properties

Wet-milling properties of corn hybrids were determined using a laboratory-scale procedure requiring 100 g (db) of corn sample, which was initially developed by Eckhoff et al. (1996) and later improved by their colleagues (Singh at al., 1997; Vignaux et al., 2006). The procedure can be briefly described as follows.

Steeping: Manually cleaned corn sample (100 g, db) and 300 mL of water containing 0.2% sodium metabisulfite and 0.5% lactic acid were placed in a 1-L capped container and left for steeping in water bath at 50 °C for 48 h. During steeping, corn kernels became softer and the hull, endosperm and germ gained respectively elastic, friable and rubbery textures, all of which facilitated ease of separation of fiber, germ, starch and gluten fractions. At the end of the steeping period, steep water was drained, measured and its dry matter content, called as "steep-water solids", was determined by oven drying.

Germ separation: Steeped and drained kernels along with 200 mL of water were then placed in 1-L cup of Waring blender with inverted blunt blades and run at about 30 % of its maximum speed, controlled with a tachometer, for 4 min. By this way, kernels were partially disassembled to release intact germs. In the following step, germs were floated due to lower density and separated from the mixture through a hand-held screen with openings of 2.8 mm. This fraction, called as "germ", was washed with 500 mL of water, dried and quantified. The wash-water was saved for use in the following step.

Fiber removal: The germ-free mixture, along with the saved wash-water, was placed in 4-L cup of Waring blender and run at its maximum speed for 3 min. This finely ground mixture was then sieved through a screen with openings of 0.3 mm and stir-washed with 1 L of water. The overs of the screen, called as "course fiber", was oven-dried and quantified. The remaining mixture that is free of germ and course fiber was sieved once more through 75-µm opening screen. The overs of this screen, called as "fine fiber", was also oven-dried and quantified. "Course fiber" and "fine fiber" fractions were then combined to obtain "total fiber".

Starch isolation: The remaining mixture, composed mainly of starch and gluten, was rested for 30 min to settle down starch and gluten in order to separate excess of water (about 2 L). The density of the mixture was adjusted to 1.040-1.045 by controlled addition of the separated water. This starch-protein mixture was then poured (50 mL/min) on a starch-gluten separation table that was set at % 1.04 of inclination. The starch-gluten separation table was a U-shaped aluminum profile that had length, width and height of 2.5 m, 4.5 cm and 2.5 cm, respectively. As the density of starch is much higher than that of gluten, starch was settled along the starch-gluten separation table, while partially solubilized gluten was carried and washed away with water. Finally, 1 L of clear water was run over the settled starch to wash away the remaining gluten atop the starch. This fraction, called as "starch", was dried at room temperature for 24 h and quantified.

Gluten recovery: The wash-water collected at the end of the starch-gluten separation table, which contains mostly gluten proteins and thus called "gluten", was oven-dried and quantified.

Through the whole process, a total of five wet-milling fractions, namely steep-water solids, germ, total fiber, starch and gluten, were obtained. Yields for these fractions [Fraction yield (%) = Amount of fraction (g, dm) / Amount of corn (g, dm) x 100] and starch recovery [Starch recovery (%) = Starch yield (%, dm) / Starch content of corn (%, dm) x 100] were calculated.

2.5. Statistical analysis

Physical, chemical and wet-milling data, obtained from dent corn hybrids grown in two locations for two years by the randomized complete block design, were subjected to analysis of variance and Duncan's multiple comparison test (Düzgüneş et al., 1987) using SPSS statistical software. The data of each location were separately analyzed and means of two-year data were reported.

3. Results and Discussion

3.1. Grain yields of dent corn hybrids grown in Adana and Sakarya

Two-year average grain yields of corn hybrids grown in Adana location varied significantly (P<0.01) from 1139 to 1481 kg^{-da} (Table 2). The hybrids P 31 G 98 and P 31 N 27 gave the highest yields, while Progen 1661, Progen 1303 and Brasco the lowest. In Sakarya location (Table 2), grain yields of two-year average also varied significantly (P<0.01), ranging from 1260 to 1670 kg^{-da}. The hybrids ADA 523, Helen, DKC 6842

Table 2. Grain yields of dent corn hybrids grown in Adana and Sakarya*
***Çizelge 2.** Adana ve Sakarya'da yetiştirilen at dişi mısır hibritlerinin tane verimleri**

No	Adana			Sakarya		
	Hybrid	Yield (kg^{-da})**		Hybrid	Yield (kg^{-da})**	
1	Arma	1304	*a-e*	Factor	1452	*cd*
2	Brasco	1166	*de*	Sancia	1430	*d*
3	DKC 6022	1246	*b-e*	Helen	1640	*a*
4	DKC 6842	1306	*a-e*	OSSK 602	1466	*bcd*
5	Helen	1372	*a-d*	Kermess	1412	*d*
6	King	1213	*cde*	P 31 G 98	1600	*a*
7	P 31 G 98	1481	*a*	Tector	1561	*abc*
8	P 31 N 27	1435	*ab*	DKC 6842	1639	*a*
9	P 31 P 41	1320	*a-e*	Shemal	1411	*d*
10	P 32 W 86	1394	*abc*	P 32 W 86	1476	*bcd*
11	Progen 1303	1164	*de*	Tietar	1463	*cd*
12	Progen 1661	1139	*e*	Cadız	1260	*e*
13	Sele	1278	*a-e*	LG 2712	1589	*ab*
14	Shemal	1290	*a-e*	DKC 6418	1569	*abc*
15	Tietar	1304	*a-e*	ADA 523	1670	*a*
	Range	1139-1481		Range	1260-1670	
	Mean	1294		Mean	1509	

*14% moisture basis. Different letters in the same column indicate significant difference ***P<0.01*; ns: not significant, *P>0.05*).

and P 31 G 98 yielded the highest, followed by LG 2712, DKC 6418 and Tector, whereas the hybrid Cadız yielded the lowest (1260 kg^{-da}). It has been well-documented by other researchers (Gözübenli et al., 1997; Sezer and Gülümser, 1999; Öz and Kapar, 2003, 2005; Alan et al., 2005; Vartanlı and Emeklier, 2007) that corn yield habitually varies by hybrids and environmental conditions.

3.2. Physical, chemical and wet-milling properties of dent corn hybrids grown in Adana

Physical properties, chemical compositions and wet-milling characteristics of corn hybrids grown in Adana location are listed in Tables 3-6. The hybrids showed significant differences (P<0.01) in terms of thousand-kernel weight, hectoliter weight, hardness and density, which are important physical traits in wet-milling of corn (Table 3).

The mean thousand-kernel weight, hectoliter weight, hardness and density of the hybrids were respectively determined to be 326.4 g, 79.4 kg, 21.1 sec and 1.29 g^{-cm3}. In wet-milling, high thousand-kernel weight and low hectoliter weight together with low hardness and density are preferred (Eckhoff, 2004). As seen in Table 11, positive significant correlations of hectoliter weight were established with hardness, density and protein content (P<0.01), positive significant correlations of hardness with density and protein content (P<0.01), negative significant correlation of hardness with starch yield (P<0.01). Similar correlations were reported by other researchers (Fox et al., 1992; Zehr et al., 1995; Arora et al., 2008). Chemical compositions (db) of the hybrids grown in Adana are seen in Table 4.

Table 3. Physical properties of dent corn hybrids grown in Adana[*]

Çizelge 3. *Adana ve Sakarya'da yetiştirilen at dişi mısır hibritlerinin fiziksel özellikleri*[*]

No	Hybrid	Thousand-kernel weight (g)[a]		Hectoliter weight (kg)		Hardness (sec)		Density (g^{-cm3})	
1	Arma	330.7	*abc***	77.4	*a***	14.5	*a***	1.26	*a***
2	Brasco	309.6	*ab*	80.2	*abc*	21.0	*bc*	1.29	*bcd*
3	DKC 6022	317.9	*abc*	79.7	*abc*	21.1	*bc*	1.28	*bcd*
4	DKC 6842	302.9	*ab*	79.3	*abc*	21.7	*bc*	1.32	*g*
5	Helen	335.3	*bc*	79.4	*abc*	21.8	*bc*	1.28	*bcd*
6	King	324.3	*abc*	79.0	*abc*	21.4	*bc*	1.27	*ab*
7	P 31 G 98	326.9	*abc*	79.0	*abc*	20.0	*bc*	1.29	*b-e*
8	P 31 N 27	353.2	*cd*	80.5	*bc*	26.2	*d*	1.31	*fg*
9	P 31 P 41	377.0	*d*	78.9	*abc*	21.0	*bc*	1.29	*cde*
10	P 32 W 86	336.4	*bc*	81.4	*c*	23.8	*cd*	1.31	*efg*
11	Progen1303	333.0	*bc*	79.9	*abc*	23.6	*cd*	1.30	*def*
12	Progen1661	329.2	*abc*	78.0	*ab*	20.3	*bc*	1.28	*ab*
13	Sele	294.9	*a*	77.2	*a*	17.4	*ab*	1.26	*a*
14	Shemal	304.7	*ab*	81.2	*c*	21.5	*bc*	1.30	*cde*
15	Tietar	320.2	*abc*	79.5	*abc*	20.5	*bc*	1.28	*bc*
	Range	294.9-377.0		77.2-81.4		14.5-26.2		1.26-1.32	
	Mean	326.4		79.4		21.1		1.29	

[*]14% moisture basis. Different letters in the same column indicate significant difference (***P<0.01*).

Table 4. Chemical compositions of dent corn hybrids grown in Adana*
Çizelge 4. *Adana ve Sakarya'da yetiştirilen at dişi mısır hibritlerinin kimyasal bileşimleri**

No	Hybrid	Protein content (%)		Starch content (%)		Fat content (%)		Ash content (%)	
1	Arma	7.7	*a***	73.3	*ns*	4.7	*e***	1.29	*abc**
2	Brasco	8.8	*bcd*	72.7		3.8	*a-d*	1.27	*ab*
3	DKC 6022	8.6	*a-d*	71.3		4.2	*a-e*	1.27	*ab*
4	DKC 6842	9.0	*cde*	72.2		3.5	*ab*	1.41	*c*
5	Helen	8.0	*ab*	72.4		3.4	*a*	1.21	*a*
6	King	8.6	*bcd*	73.9		4.1	*a-e*	1.37	*bc*
7	P 31 G 98	8.5	*a-d*	73.4		4.1	*a-e*	1.33	*abc*
8	P 31 N 27	9.0	*cde*	72.7		3.6	*ab*	1.31	*abc*
9	P 31 P 41	8.5	*a-e*	72.6		3.8	*a-e*	1.21	*a*
10	P 32 W 86	9.4	*def*	71.1		4.5	*cde*	1.38	*bc*
11	Progen1303	10.3	*g*	72.3		3.8	*a-e*	1.33	*ab*
12	Progen1661	10.2	*fg*	72.1		3.7	*abc*	1.34	*bc*
13	Sele	8.2	*abc*	72.0		4.3	*b-e*	1.27	*abc*
14	Shemal	9.2	*de*	71.9		4.0	*a-e*	1.26	*ab*
15	Tietar	9.8	*efg*	70.4		4.6	*cd*	1.32	*abc*
	Range	7.7-10.3		70.4-73.9		3.4-4.7		1.21-1.41	
	Mean	8.9		72.3		4.0		1.30	

[a]Based on dry matter. Different letters in the same column indicate significant difference (**P<0.05*; ***P<0.01*; ns: not significant, *P>0.05*).

Protein contents of the hybrids varied from 7.7 to % 10.3, starch contents from 70.4 to % 73.9, fat contents from 3.4 to % 4.7 and ash contents from 1.21 to % 1.41. These values are typical of dent corn hybrids (Singh et al., 1997; Singh, 1999; Eckhoff, 2004). The differences in protein, fat and ash contents of the hybrids were significant (P<0.01), while the differences in starch contents were statistically insignificant (P>0.05). Given the fact that hybrids with higher starch and lower protein contents are desirable in wet-milling (Sayaslan and Gökmen, 2008; Eckhoff, 2004, Morris, 2004), the hybrids Arma, Helen and Sele are promising with their lower protein contents. As listed in Table 11, negative significant correlations (P<0.01) of protein content with starch content, yield and recovery, while positive correlation (P<0.05) of starch content with starch yield were established, which are comparable to the results of Fox et al. (1992), Zehr et al. (1995) and Arora et al. (2008).Wet-milling properties of corn hybrids are given in Tables 5 and 6.

The hybrids showed significant differences (P<0.05 or P<0.01) in the yields of steep-water solids, germ, gluten and starch, yet no significant difference (P>0.05) was observed in other wet-milling parameters, i.e., total fiber yield, starch recovery or purity and wet-milling recovery. When the hybrids were assessed in terms of yield, recovery and purity of starch, which are the main determinants of wet-milling quality (Sayaslan, 2004; Sayaslan and Gökmen, 2008; Singh, 1999), the hybrids Helen, P 31 P 41, P 31 G 98, P 31 N 27 and P 32 W 86 were found to be superior to the other hybrids grown in Adana.

Table 5. Wet-milling properties of dent corn hybrids grown in Adana - distribution of nonstarch wet-milling fractions*

Çizelge 5. *Adana'da yetiştirilen at dişi mısır hibritlerinin yaş-öğütme özellikleri – nişasta harici yaş-öğütme fraksiyonlarının dağılımı**

No	Hybrid	Steep-water solids yield (%)		Germ yield (%)		Total fiber yield (%)		Gluten yield (%)	
1	Arma	4.6	*abc***	7.6	*abc***	11.6	*ns*	15.0	*abc***
2	Brasco	4.8	*abc*	6.5	*ab*	11.3		17.3	*bc*
3	DKC 6022	5.2	*c*	7.1	*abc*	10.9		16.4	*abc*
4	DKC 6842	4.9	*bc*	8.0	*bc*	10.8		15.6	*abc*
5	Helen	4.6	*abc*	6.1	*a*	11.7		12.8	*a*
6	King	5.1	*c*	7.4	*abc*	10.6		15.7	*abc*
7	P 31 G 98	5.0	*bc*	8.4	*c*	10.2		13.7	*abc*
8	P 31 N 27	5.1	*bc*	7.0	*abc*	10.4		13.9	*abc*
9	P 31 P 41	4.5	*abc*	7.9	*bc*	10.6		13.0	*ab*
10	P 32 W 86	5.1	*c*	8.0	*bc*	11.5		14.0	*abc*
11	Progen1303	4.4	*ab*	7.4	*abc*	11.5		17.3	*bc*
12	Progen1661	4.1	*a*	8.7	*c*	9.3		17.7	*c*
13	Sele	4.5	*abc*	7.7	*abc*	12.4		14.5	*abc*
14	Shemal	4.9	*bc*	6.4	*ab*	12.1		16.5	*abc*
15	Tietar	4.7	*abc*	7.9	*bc*	11.3		17.0	*abc*
	Range	4.1-5.2		6.4-8.7		9.3-12.4		12.8-17.7	
	Mean	4.8		7.5		11.1		15.3	

*Based on dry matter. Different letters in the same column indicate significant difference (***P<0.01*; ns: not significant, *P>0.05*).

Table 6. Wet-milling properties of dent corn hybrids grown in Adana - distribution of starch fraction*

Çizelge 6. *Adana'da yetiştirilen at dişi mısır hibritlerinin yaş-öğütme özellikleri – nişasta fraksiyonu dağılımı**

No	Hybrid	Starch yield (%)		Starch purity (protein; %)		Starch recovery (%)		Wet-milling process recovery (%)	
1	Arma	61.4	*a-d**	0.26	*ns*	83.9	*ns*	100.2	*ns*
2	Brasco	60.1	*abc*	0.34		82.7		100.0	
3	DKC 6022	61.1	*a-d*	0.33		85.8		100.7	
4	DKC 6842	61.4	*a-d*	0.29		85.1		100.7	
5	Helen	64.8	*d*	0.31		89.6		99.9	
6	King	60.9	*a-d*	0.22		82.4		99.6	
7	P 31 G 98	63.2	*bcd*	0.29		86.2		100.5	
8	P 31 N 27	62.6	*a-d*	0.30		86.2		99.0	
9	P 31 P 41	63.9	*cd*	0.28		88.2		100.0	
10	P 32 W 86	62.0	*a-d*	0.32		87.4		100.5	
11	Progen1303	59.2	*ab*	0.30		82.1		99.7	
12	Progen1661	60.5	*abc*	0.39		84.0		100.4	
13	Sele	60.7	*abc*	0.31		84.3		99.8	
14	Shemal	60.7	*a-d*	0.37		84.5		100.5	
15	Tietar	58.7	*a*	0.35		83.4		99.6	
	Range	58.7-64.8		0.22-0.39		82.1-89.6		99.6-100.7	
	Mean	61.4		0.31		85.0		100.1	

[a]Based on dry matter. Different letters in the same column indicate significant difference (***P<0.01*; ns: not significant, *P>0.05*).

3.3. Physical, chemical and wet-milling properties of dent corn hybrids grown in Sakarya

Physical, chemical and wet-milling properties of the hybrids grown in Sakarya location are listed in Tables 7-10. The hybrids displayed significant differences (P<0.01 or P<0.05) in terms of thousand-kernel weight, hardness and density, which are of importance in wet-milling quality; however, no difference (P>0.05) was detected in hectoliter weight (Table 7).

Table 7. Physical properties of dent corn hybrids grown in Sakarya*
Çizelge 7. *Sakarya'da yetiştirilen at dişi mısır hibritlerinin fiziksel özellikleri**

No	Hybrid	Thousand-kernel weight (g)[a]		Hectoliter weight (kg)		Hardness (sec)		Density (g^{-cm3})	
1	Factor	370.0	*ab**	76.2	*ns*	20.3	*a***	1.29	*cd***
2	Sancia	331.7	*a*	75.5		21.7	*ab*	1.26	*ab*
3	Helen	393.9	*c*	77.4		23.1	*ab*	1.30	*cd*
4	OSSK 602	377.7	*bc*	75.1		19.5	*a*	1.25	*a*
5	Kermess	362.9	*abc*	78.6		22.5	*ab*	1.30	*cd*
6	P 31 G 98	390.0	*bc*	77.4		22.2	*ab*	1.30	*cd*
7	Tector	375.6	*bc*	80.1		25.8	*bc*	1.31	*cde*
8	DKC 6842	363.6	*abc*	78.2		28.3	*c*	1.33	*e*
9	Shemal	368.0	*abc*	80.1		21.3	*ab*	1.31	*cd*
10	P 32 W 86	358.5	*abc*	79.0		23.8	*abc*	1.31	*de*
11	Tietar	359.7	*abc*	77.8		23.1	*ab*	1.29	*bcd*
12	Cadız	351.1	*ab*	79.2		23.2	*ab*	1.31	*cd*
13	LG 2712	359.9	*abc*	78.4		20.8	*ab*	1.30	*cd*
14	DKC 6418	397.6	*c*	78.4		20.8	*ab*	1.30	*cd*
15	ADA 523	370.4	*abc*	76.6		19.3	*a*	1.28	*bc*
	Range	331.7-397.6		75.1-80.1		19.3-28.3		1.25-1.33	
	Mean	368.7		77.9		22.4		1.30	

*14% moisture basis. Different letters in the same column indicate significant difference (**P<0.05*; (***P<0.01*; ns: not significant, *P>0.05*).

The average thousand-kernel weight, hectoliter weight, hardness and density of the hybrids were respectively 368.7 g, 77.9 kg, 22.4 sec and 1.30 g^{-cm3}. Among the hybrids, DKC 6418 and Helen had the highest thousand-kernel weight, while Sancia had the lowest.

As seen in Table 8, dent corn hybrids grown in Sakarya showed significant differences in fat (P<0.01) and ash (P<0.05) contents; yet they contained similar (P>0.05) levels of protein (7.6-8.9%) and starch (70.5-74.8%). The hybrids contained average of 8.3% protein, 72.8% starch, 4.2% fat and 1.30% ash, all of which were based on dry basis. Lower protein and higher starch contents are preferred in wet-milling for higher starch yield and recovery (Sayaslan and Gökmen, 2008; Eckhoff, 2004, Morris, 2004). In this regard, no significant difference (P>0.05) were detected among the corn hybrids grown in Sakarya. Wet-milling characteristics of dent corn hybrids grown in Sakarya are summarized in Tables 9 and 10.

Table 8. Chemical compositions of dent corn hybrids grown in Sakarya*

Çizelge 8. *Sakarya'da yetiştirilen at dişi mısır hibritlerinin kimyasal bileşimleri**

No	Hybrid	Protein content (%)		Starch content (%)		Fat content (%)		Ash content (%)	
1	Factor	8.2	*ns*	74.8	*ns*	4.1	*a-d***	1.30	*a-d**
2	Sancia	7.6		72.5		3.8	*ab*	1.33	*a-d*
3	Helen	8.6		75.2		3.9	*ab*	1.45	*cd*
4	OSSK 602	8.1		70.5		4.0	*a-d*	1.27	*a-d*
5	Kermess	7.9		70.8		3.4	*a*	1.28	*a-d*
6	P 31 G 98	8.6		72.6		4.5	*bcd*	1.21	*a*
7	Tector	8.2		73.2		4.0	*a-d*	1.20	*a*
8	DKC 6842	8.1		72.8		4.4	*bcd*	1.34	*a-d*
9	Shemal	8.2		72.7		4.0	*abc*	1.44	*bcd*
10	P 32 W 86	8.8		73.2		4.5	*bcd*	1.46	*d*
11	Tietar	8.9		71.9		4.7	*cd*	1.30	*a-d*
12	Cadız	8.3		71.6		4.4	*bcd*	1.26	*ab*
13	LG 2712	8.0		73.6		4.7	*d*	1.26	*ab*
14	DKC 6418	8.0		73.4		4.3	*bcd*	1.24	*a*
15	ADA 523	8.6		74.0		4.4	*bcd*	1.22	*a*
	Range	7.6-8.9		70.5-74.8		3.4-4.7		1.20-1.46	
	Mean	8.3		72.8		4.2		1.30	

*Based on dry matter. Different letters in the same column indicate significant difference (**P<0.05*; ***P<0.01*; ns: not significant, *P>0.05*).

Tablo 9. Wet-milling properties of dent corn hybrids grown in Sakarya - distribution of nonstarch wet-milling fractions*

Çizelge 9. *Sakarya'da yetiştirilen at dişi mısır hibritlerinin yaş-öğütme özellikleri – nişasta harici yaş-öğütme fraksiyonlarının dağılımı**

No	Hybrid	Steep-water solids yield (%)		Germ yield (%)		Total fiber yield (%)		Gluten yield (%)	
1	Factor	4.3	*a***	6.2	*a***	10.6	*a-d**	14.9	*ns*
2	Sancia	4.5	*ab*	7.3	*bcd*	10.3	*a-d*	14.9	
3	Helen	4.5	*ab*	7.1	*a-d*	9.9	*a-d*	14.0	
4	OSSK 602	4.8	*abc*	6.8	*abc*	11.3	*cd*	15.5	
5	Kermess	4.5	*ab*	6.6	*ab*	9.1	*a*	16.2	
6	P 31 G 98	5.3	*bc*	7.7	*bcd*	10.6	*a-d*	13.0	
7	Tector	4.9	*abc*	6.8	*abc*	10.8	*bcd*	15.1	
8	DKC 6842	4.9	*abc*	8.0	*de*	11.3	*d*	12.5	
9	Shemal	4.8	*abc*	7.4	*bcd*	9.4	*ab*	14.6	
10	P 32 W 86	4.8	*abc*	9.0	*f*	9.6	*abc*	13.5	
11	Tietar	5.6	*c*	8.9	*ef*	10.5	*a-d*	13.8	
12	Cadız	4.4	*ab*	7.6	*bcd*	10.2	*a-d*	14.5	
13	LG 2712	4.8	*abc*	7.9	*cde*	9.1	*a*	14.0	
14	DKC 6418	4.4	*ab*	7.6	*bcd*	9.5	*ab*	13.6	
15	ADA 523	4.1	*a*	8.0	*de*	11.0	*bcd*	14.2	
	Range	4.1-5.6		6.2-9.0		9.1-11.3		12.5-16.2	
	Mean	4.7		7.5		10.2		14.3	

*Based on dry matter. Different letters in the same column indicate significant difference (**P<0.05*; ***P<0.01*; ns: not significant, *P>0.05*).

Table 10. Wet-milling properties of dent corn hybrids grown in Sakarya - distribution of starch fraction*
Çizelge 10. *Sakarya'da yetiştirilen at dişi mısır hibritlerinin yaş-öğütme özellikleri – nişasta fraksiyonu dağılımı**

No	Hybrid	Starch yield (%)	Starch purity (protein; %)	Starch recovery (%)	Wet-milling process recovery (%)
1	Factor	64.6 *ns*	0.30 *ns*	86.5 *ns*	100.5 *ns*
2	Sancia	62.5	0.25	86.4	99.5
3	Helen	64.3	0.26	85.7	99.8
4	OSSK 602	61.4	0.26	87.5	99.8
5	Kermess	63.9	0.23	90.5	100.3
6	P 31 G 98	63.4	0.27	87.5	100.0
7	Tector	62.7	0.27	85.6	100.3
8	DKC 6842	63.4	0.30	87.2	100.1
9	Shemal	63.1	0.29	86.9	99.1
10	P 32 W 86	63.7	0.24	87.2	100.7
11	Tietar	61.0	0.24	85.0	99.9
12	Cadız	63.5	0.31	88.9	100.1
13	LG 2712	63.8	0.27	87.0	99.6
14	DKC 6418	64.9	0.27	88.6	100.0
15	ADA 523	62.7	0.31	84.9	100.0
	Range	61.0-64.9	0.23-0.31	84.9-90.5	99.5-100.7
	Mean	63.3	0.27	87.0	99.8

*Based on dry matter. Different letters in the same column indicate significant difference (ns: not significant, *P>0.05*).

Among the hybrids, significant differences (P<0.05) were observed only in the yields of steep-water solids, germ and total fiber. However, no significant difference (P>0.05) was found in terms of starch yield, purity and recovery, all of which are major indicators of corn wet-milling quality (Sayaslan and Gökmen, 2008; Singh, 1999). This finding is indeed in agreement with the indifferences detected in the starch and protein contents of the hybrids (Table 8). In conclusion, wet-milling qualities of the dent corn hybrids grown in Sakarya were quite similar.

4. Conclusions

Physical, chemical and wet-milling qualities of dent corn hybrids grown in Adana and Sakarya were investigated. The hybrids grown in Adana showed significant differences in their physical, chemical and wet-milling properties. Wet-milling qualities of the hybrids Helen, P 31 P 41, P 31 G 98, P 31 N 27 and P 32 W 86 were superior to the other hybrids in Adana. On the other hand, the hybrids grown in Sakarya showed no significant difference in their starch yields, purities and recoveries, indicating similar wet-milling qualities, although they exhibited significant differences in certain physical and chemical properties. Additionally, significant correlations were established among certain physical, chemical and wet-milling quality parameters of dent corn hybrids. In this manner, positive correlations of hectoliter weight with hardness, density and protein content, negative correlations of protein content with starch content, yield and recovery, positive correlation of starch content with starch yield were of noteworthy.

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Table 11. Correlations (r) among physcial, chemical and wet-milling parameters of dent corn hybrids grown in Adana and Sakarya (n=30)
Çizelge 11. Adana ve Sakarya'da yetiştirilen at dişi mısır hibritlerinin fiziksel, kimyasal ve yaş-öğütme parametreleri arasındaki korelasyonlar (r, n=30)

	Thousand kernel weight	Hectoliter weight	Hardness	Density	Protein content	Starch content	Fat content	Ash content	Steep water solids yield	Germ yield	Total fiber yield	Gluten yield	Starch yield	Starch purity	Starch recovey	Wet milling process recovery
Thousand kernel wt.	1	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Hectoliter weight		1	**0.57****	**0.66****	**0.53****	-0.44**	ns	ns	ns	ns	ns	ns	-0.33*	0.47**	ns	ns
Hardness			1	**0.64****	**0.61****	-0.30**	-0.31*	0.39**	ns	ns	ns	ns	-0.45**	ns	-0.03*	ns
Density				1	0.32*	ns	ns	ns	ns	ns	ns	ns	ns	0.43*	ns	ns
Protein content					1	**-0.52****	ns	ns	ns	0.39**	ns	**0.61****	**-0.78****	**0.56****	**-0.57****	ns
Starch content						1	ns	ns	ns	ns	ns	**-0.51****	**0.51****	-0.30*	ns	ns
Fat content							1	ns	ns	0.31**	ns	-0.27*	ns	ns	ns	ns
Ash content								1	ns	0.45**	ns	0.48**	**-0.50****	ns	-0.47**	ns
Steep-water solids yield									1	ns	ns	ns	ns	ns	ns	ns
Germ yield										1	ns	ns	-0.27*	ns	ns	ns
Total fiber yield											1	ns	-0.47**	ns	**-0.57****	ns
Gluten yield												1	**-0.73****	0.78**	**-0.56****	ns
Starch yield													1	-0.36**	**0.80****	ns
Starch purity														1	-0.56*	ns
Starch recovery															1	ns
Wet-milling process recovery																1

*P<0.05; **P<0.01; ns: not significant, *P>0.05*

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