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Yield and Quality Performance of Traditional and Improved Bread and Durum Wheat Varieties under Two Conservation Tillage Systems

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Abstract: The increasing spread of conservation agriculture demands that the next generation of wheat varieties includes cultivars capable of maintaining satisfactory yields with lower inputs and under uncertain climate scenarios. On the basis of the genetic gains achieved during decades of selection oriented to yield improvements under conventional crop management, it is important that novel breeding targets are defined and addressed. Grain yield, yield-related traits, and phenological and morphological characteristics, as well as functional quality parameters have been analyzed for six varieties each of bread and durum wheat, under minimum tillage and no-tillage. During the three-year experiment, the climatic conditions at the field trial site were characterized by low rainfall, although different degrees of aridity—from moderate to severe—were experienced. Differences were found between these two soil management practices in regard to the varieties' yield stability. A positive influence of no-tillage on traits related to grain and biomass yield was also evidenced, and some traits among the examined seemed involved in varietal adaptation to a particular non-conventional tillage system. The study also confirmed some breeding targets for improved performance of wheat genotypes in conservation agroecosystems. These traits were represented in the small set of traditional varieties analysed.

Keywords: landraces; yield components; quality parameters; conservation agriculture; soil quality; no-tillage; minimum tillage; drought

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1. Introduction

Cropland soils have low organic matter content in many dry and semi-arid areas, like the Mediterranean zone, due to climatic limitations that affect net primary productivity. Water deficit and low soil fertility make these agroecosystems vulnerable, both to cyclic drought events and the current process of global climate change. With degraded soils and unpredictable weather patterns, return on investment is uncertain, which increases the economic and social risks for farmers. Under such conditions, one approach to improve crop production, while minimizing soil and other natural resources degradation, is to adopt crop-nutrient-water-land management practices that are collectively included in the term 'conservation agriculture' [1]. The practice is not only effective in enhancing soil quality and increasing farmer gains (by reucing production costs), but has also been identified by some governments as a solution to the serious environmental problems that currently affect many farmlands [2], becoming a major research issue in the 21st century for leading crops like wheat [3].

Soil conservation agriculture encompasses techniques that reduce or eliminate tillage (minimum and no-tillage practices) and maintain a vegetation cover that protects soil from degradation [2]. Both conservation tillage practices have overall positive effects on main soil functions: carbon sequestration and climate regulation, nutrient cycling and provision, water regulation and purification, and habitats for functional and intrinsic biodiversity [4]. In contrast, continuous soil tillage and residue removal (conventional tillage) is characterized by higher production costs, and has a negative effect on soil properties and the environment, resulting in soil degradation and water and wind erosion, which can limit crop production [4–7]. A recent global meta-analysis of no-tillage (NT) compared to conventional tillage reported that the former, in combination with crop rotation, increases rain-fed crop productivity in dry climates, suggesting that it may become an important climate-change adaptation strategy for drier regions of the world [8]. When farmers change from conventional to conservation techniques for wheat production, they often choose minimum tillage (MT) because it offers easier adaptation of machinery [7]. Nevertheless, the few studies that compare these two conservation tillage systems have reported that they can have differential positive effects on soil functions and crop yield in diverse environments [4,6,7,9,10].

Very few reports have evaluated genotype responses to tillage systems (see review [11]). Most of them have used modern varieties developed under conventional systems, and usually one single cultivar, so the variety effect is little studied [12]. Clearly, there is the need for more studies that extensively compare genotypes under different conservation tillage systems. This will aid the identification of crop traits associated with superior performance to facilitate the genetic improvement of varieties adapted to alternative, non-conventional, agriculture systems [11]. In this novel context, an appropriate varietal choice must respond not only to productivity criteria, but also to sustainability, characterized by yield stability, soil quality and resilience to cope with new challenges caused by the actual uncertainty of future climate scenarios [1]. The intensive spread and wide use of improved, modern varieties has led to a genetic bottleneck, resulting in the loss of crop diversity (see [13] for review). In wheat, breeding efforts over the last century have resulted in a huge improvement in the crop's response to high-input environments. However, this has been achieved at the expense of reducing genetic heterogeneity, thus increasing crop vulnerability [14]. Landraces, traditionally grown with less artificial resource inputs, are genetically diverse repositories of unique traits that have evolved in local environments characterized by a wide range of biotic and abiotic conditions [1,13]. Different studies have shown that Mediterranean wheat landraces represent a particularly important group of genetic resources, where extensive genetic variability [15–17] as well as tolerance to drought [17], diseases resistances [18] and adaptability to low-input farming systems [19,20] has been documented. These varieties have also shown a large potential for enhancing C sequestration and reducing the C footprint through high residue production [21]. It thus seems reasonable to consider that landraces widely cultivated in Mediterranean rainfed conditions can provide genetic resources for enlarging crop diversity and plant traits to improve crop adaptation to conservation agriculture.

With the above in mind, the purposes of this research were: (a) to evaluate the yield and quality performance of a set of bread and durum wheat varieties, including traditional genotypes, under two conservation tillage managements (MT and NT) in rainfed conditions; and (b) to identify yield components and agronomic traits linked to the improved response under these types of conservation tillage. The results have shown the predominant roles of climatic conditions and genotype on the yield and quality performance of a wheat cultivar, whatever the non-conventional tillage system used. Nevertheless, differences between the minimum and no-tillage soil management systems were found, especially regarding yield stability of the varieties, and some grain and biomass yield-related traits that may be relevant for better variety adaptation to one of these tillage systems. The study has also evidenced that some agronomic traits may be breeding targets for improved performance of wheat varieties in conservation agroecosystems. Interestingly, these traits were represented in the small set of landraces examined.

2. Materials and Methods

2.1. Materials

Six varieties of bread wheat (*Triticum aestivum* L.) and six of durum wheat (*Triticum turgidum* L.) widely cultivated in Spain, either in the past or the present, were selected (Table 1). According to their year of release, these varieties were designed as: landraces (released before 1950), intermediate (released between 1970 and 1990) and modern (released after 1990). The two bread wheat landraces used (Aragon-03 and Chamorro) are registered as commercial varieties, considering their good reputation in the past. The bread wheat genotypes Berdun, Marius, Aragon-03 and Chamorro have a winter growth habit, whereas Califa Sur and Yecora, and all the durum wheat genotypes are spring varieties [22,23].

Table 1. Class of varieties according to released date and growth habit of the 12 genotypes of bread and durum wheat included in the study.

	Class	Variety	Growth Habit
Bread wheat	landraces	Chamorro	winter
		Aragon-03	winter
	intermediate	Yecora	spring
		Marius	winter
	modern	Berdun	winter
		Califa Sur	spring
Durum wheat	landraces	Senatore Capelli	spring
		Jerez-36	spring
	intermediate	Cocorit	spring
		Vitron	spring
	modern	Don Pedro	spring
		Avispa	spring

2.2. Site Description and Experimental Procedure

The study was performed at the INIA experimental farm La Canaleja (Alcalá de Henares, Madrid, Spain: 40°32′ N and 3°20′ W; 600 m). The soil is a sandy-loam Calcic Haploxeralf, pH 8 with low inherent fertility. The climate of the area is semi-arid continental-Mediterranean with dry summers. Precipitations are irregularly distributed over the year and from one year to another. The average rainfall over the last 25 years is 365 mm per year, the annual precipitation being below the average 11 years during that period (1994–2018). Daily meteorological data were recorded over the period of study (autumn 2015 to summer 2018) at the weather station located in the growing area. The average monthly precipitation, and minimum and maximum temperatures from October to June are shown in Figure S1 (Supplementary Material). For environment characterization, some agroclimatic variables were estimated for two growing periods: from sowing to anthesis (SA) (Zadoks stage 65; [24] and from anthesis to physiological maturity (AM) (Zadoks stage 87). The mean dates of anthesis and physiological maturity of all plots were used to define the SA and AM periods in each environment (i.e., agronomic year) [25]. The variables calculated for these two growing periods were: length of growing season expressed as thermal time (LGS, GDD growing degree-days), average daily mean, maximum and minimum temperatures (Tm, Tmax and Tmin, respectively, °C), mean daily relative air humidity (RH, %), average daily rainfall (Rainfall, mm) and potential evapotranspiration (ETo, mm) estimated by the Pemnan-Monteith method [26]. Thermal-time was calculated by summing the GDD accumulated during the period of interest. For a given day, GDD were calculated as the difference between the average air temperature and the base temperature [27], considering 0 °C as the base temperature. When calculating the average air temperature, the upper limit for Tmax was established at 25 °C [28].

The study, conducted over three seasons (2015–2016, 2016–2017 and 2017–2018), was designed on the basis of a split-plot randomized complete block, with three blocks divided into two plots of 1008 m^2 (67.2 m width and 15 m length). Each plot was divided into two equal parts (504 m^2), where fallow-wheat rotation was alternated during the study. Experimental treatments included two tillage practices (minimum tillage and no-tillage), which were assigned to the main plots, and 12 wheat genotypes in subplots of 42 m^2 (16 rows of 15 m length and 17.5 cm row spacing). Minimum tillage (MT) consisted of chisel ploughing at a depth of 15 cm, while no-tillage (NT) consisted of direct seeding. Fallow and tillage practices were established two years before the study.

Wheat was sown in autumn and harvested in June. Fertilizer was applied before sowing (200 kg ha^{-1} of NPK 8-24-8) and in spring (200 kg ha^{-1} of 26% ammonium nitrosulphate). Weeds were controlled according to the tillage type: by a cultivator pass before sowing and post-emergence herbicides in MT, and by herbicide in NT. During the fallow seasons, weeds were controlled with chisel and herbicides in MT and NT plots, respectively. After harvesting, all crop residues were chopped and left on the soil surface, regardless of the tillage system. No fungicides or insecticides were applied during the experiment. Figure S2 (Supplementary Material) shows images of the field trials during the three-year experiment.

2.3. Soil Properties

Soil samples were collected at the end of March in the second season (2016–2017), between the wheat stages of stem elongation and ear development (Zadoks stages 39 to 47). Soil samples were taken from the six crop plots, covering the two tillage practices and the three blocks. For each plot, soil samples were taken from three locations in a zig-zag pattern at depths of 0–15 cm and 15–30 cm. Composite soil samples were air-dried and ground to pass a 2-mm mesh. A portion of the dried ground soil was then milled for soil organic carbon (SOC) and nitrogen analysis. SOC concentration was determined using the Walkley-Black wet oxidation method. Total soil N (SN) was determined by the Kjeldahl method [29]. Soil ammonium ($N\text{-}NH_4^+$) and nitrate ($N\text{-}NO_3^-$) content was first extracted with KCl 2 M and then determined with an autoanalyser (FIAStar 5000). Additional soil variables were also determined, including C/N ratio, and P (Olsen method), assimilable K, Mg and Ca concentration [30].

After grain harvest in the third year, the saturation time (s) and rate of water infiltration in the soil surface (L s^{-1}) were measured in wheat and fallow plots using a metal ring 53 cm in diameter [31]. Saturation time was the time required for visible soil surface saturation—when the water poured into the ring starts to run off outside the ring. Water infiltration rate was determined as the quotient between the volume of water infiltrated (water poured into the ring) and the saturation time. At least three measures following a zig-zag pattern were taken from each tillage system and block to calculate average values.

2.4. Yield Components and Agronomic Traits

The plants contained in a one-meter-long row were cut at the ground level. The number of tillers and spikes in each sample were counted, and the aerial portion was weighted after being oven-dried at 70 °C for 48 h. The following yield components were calculated for each replicate: Grain weight expressed on a 12% moisture basis (GW, g m^{-2}), tiller number (TN, m^{-2}), spike number (SN, m^{-2}), grain number (GN, m^{-2}), number of grains per spike (GS), biomass weight (BW, g m^{-2}), harvest index (HI, GW: BW ratio), thousand kernel weight (TKW, g) and test weight (TW, kg hL^{-1}).

Days to heading (DH) and maturity (DM) were recorded when more than 50% of the main spikes within a plot had reached Zadoks stage 55 and 87, respectively. The grain filling period (GF, days) was estimated as the number of days between anthesis and maturity. Grain filling rate (GFR, mg GDD^{-1}) was then obtained as the quotient between average dry weight per grain and thermal time from anthesis to maturity. At harvest maturity, five plants chosen at random from the centre of the plots were used for determining plant height (PH, cm) and peduncle length (PL, cm). PH was measured from the ground level to the top of the main spike, excluding awns, and PL from the uppermost (last) node on the stem to the spike collar.

2.5. Technological Quality Evaluation

Grain protein content (GPC, % at 14% moisture basis) was measured in wholemeal flour samples by near-infrared reflectance analysis using the Technichon Infranalyzer 300. Gluten strength was evaluated by the sodium dodecyl sulfate sedimentation volume (SDSS, mm) test [32]. GPC was analyzed individually in the three replicated plots, while one single flour sample was analyzed for SDSS per genotype and tillage system. For both parameters, technical duplicates were prepared.

To analyse the glutenin composition of the wheat genotypes, endosperm proteins were extracted from wholemeal flours [33]. Electrophoresis of reduced and alkylated glutenins (high molecular weight subunits, HMW-GS, and low molecular weight subunits, LMW-GS) was performed on sodium dodecyl sulphate polyacrylamide gel electrophoresis SDS-PAGE (12% polyacrylamide gels). The alleles at the *Glu-1* loci, controlling the HMW-GS, and at *Glu-3* and *Glu-B2* loci, controlling LMW-GS, were identified [34].

2.6. Data Analyses

Analysis of variance of plant-evaluated data (i.e., agronomic and quality traits) was performed separately for bread and durum wheat, using the generalized linear mixed model with tillage treatments, genotype and year (i.e., environment) considered as fixed effects and the block as a random variable. Genotype means were compared within the same species by Fisher's protected least significant difference. Similar statistical approaches were followed to determine the effects of depth and tillage treatment, and their interactions, on soil properties and to compare soil composition data.

Multivariate analysis with principal component analyses (PCA) was applied to analyse the relationships between agronomic variables and wheat genotypes under minimum tillage and no tillage in different environments. The sampling adequacy of individual and set variables were verified by the Kaiser-Meyer-Olkin measure (>0.50) and Bartlett's test of sphericity (<0.05). Selected main components had eigenvalues over 1.0. All variables had communality values > 0.5, except for TW in durum wheat under MT in 2017–2018 (TW was removed from that analysis). Cophenetic correlation coefficients were higher than 0.9 in all the PCAs.

Relationships between variables were examined using Pearson correlation coefficients ($p < 0.05$).

Yield stability of the varieties, based on grain weight per square meter (GW) data, was analyzed by Wricke's ecovalence (W_i; [35]). This statistic estimates the sums of squares contribution of each genotype to the overall G × E term. The lower the value of W_i, the smaller the fluctuations from the predictable yield response in different environments:

$$Wi = \sum j\ (Yij - \bar{Y}i. - \bar{Y}.j + \bar{Y}..)^2 = \sum i\ gij^2 \quad (1)$$

For grain yield, the genotype × year interaction was partitioned according to the AMMI model (additive main effects and multiplicative interaction model) [36], and the percentage of the sum of squares explained by each interaction principal component axis (IPCA) was calculated for each species. Factorial regression analyses were performed to identify the agroclimatic variables with a major effect on the grain yield of wheat genotypes in different years. For these analyses, the agroclimatic data corresponding to the sowing to anthesis and anthesis to maturity periods were considered.

Data were analyzed using Infostat version 6.12 software [37]. This was also the software employed for graphical representations of the results.

3. Results

3.1. Environment Conditions and Soil Properties

Rainfall during the crop cycle (October to June) was 292 mm, 203 mm and 374 mm for the seasons 2015–2016, 2016–2017 and 2017–2018, respectively. For reasonable wheat growing, 300 mm is enough, provided that most water input is during spring [38]. Accordingly, water input was adequate in the first and third years, but in the second year, characterised by being especially dry and hot, wheat plants likely suffered severe drought stress (Figure S1, Supplementary Material). These climatic differences affected the duration of the crop cycle, the first and third years having longer pre-anthesis and post-anthesis periods measured in thermal time (Table S1, Supplementary Material).

The soil analyses carried out in the second year indicated that SN, N-NO_3^-, SOC, P and K decreased significantly with an increase in soil depth. Higher N-NO_3^- and P concentration at surface soil depth (0–15 cm) was observed under no-tillage (Table 2). Significantly higher values of saturation time were observed in the crop plots under NT when water infiltration properties were determined on soils after the crop harvest of the third year. The rate of water infiltration from the surface also increased under NT, although the differences compared to MT were not statistically significant (Figure S3, Supplementary Material).

Table 2. Mean values of soil components at two soil depths under minimum tillage (MT) and no-tillage (NT) systems.

	SN (g kg^{-1})	N-NO_3^- (mg kg^{-1})	N-NH_4^+ (mg kg^{-1})	SOC (g kg^{-1})	C/N	P (mg kg^{-1})	K (mg kg^{-1})	Mg (mg kg^{-1})	Ca (g kg^{-1})
Depth									
0–15 cm	0.53 [a,†]	5.82 [a]	6.63	4.91 [a]	9.17	6.38 [a]	250.84 a	166.21	6.10
15–30 cm	0.49 [b]	3.56 [b]	5.33	4.32 [b]	8.88	2.91 [b]	189.38 b	165.03	6.40
Tillage									
MT	0.48	2.93	5.15	4.19	8.72	3.88	200.04	155.58	6.39
NT	0.54	6.45	6.81	5.04	9.33	5.40	240.18	175.67	6.10
Depth × Tillage									
MT 0–15 cm	0.50	3.22 [b]	5.67	4.43	8.84	5.40 [a,b]	222.70	146.20	5.75
MT 15–30 cm	0.46	2.64 [b]	4.63	3.95	8.60	2.36c	177.38	164.97	7.03
NT 0–15 cm	0.56	8.43 [a]	7.58	5.38	9.51	7.35a	278.98	186.23	6.44
NT 15–30 cm	0.51	4.48 [b]	6.04	4.70	9.15	3.46bc	201.38	165.10	5.76

† Values within columns followed by different letters are significantly different at $p = 0.05$. SN = Soil nitrogen, N-NO_3^- = Nitrogen as nitrate, N-NH_4^+ = Nitrogen as ammonium, SOC = Soil organic carbon, C/N = Carbon/Nitrogen ratio, P = Phosphor (Olsen), K = Potassium, Mg = Magnesium, Ca = Calcium.

3.2. Grain Yield and Agronomic Traits

Table 3 shows the mean values of all the variables analysed for each year. The mean values obtained for each variety of bread and durum wheat in the three years of experiment are provided as Supplementary Material (Figure S4).

These results evidenced the remarkable influence of the environmental conditions that occurred during the study on yield and all the other agronomic traits evaluated, which was further confirmed by the analyses of variance performed (Table S2, Supplementary Material). Variability of climatic conditions among the years significantly affected grain weight (GW) and yield components. Lower values were recorded in the driest and hottest second year (2016–2017) for all the traits in both species (Table 3). The highest values for HI, TKW and TW were obtained in the rainiest third year (2017–2018), while no significant differences were found for GW, GN and BW between the first and third years.

The morphology and phenology of bread and durum wheat plants were also influenced by extreme water stress in the second year, which reduced all the measured values.

All the yield-related traits were significantly affected by the genotype (except TN, SN and BW in durum wheat), and some of them showed a significant genotype × year interaction (Table S2, Supplementary Material). In bread wheat, the winter genotypes (especially Marius) had higher GW values in the more humid years (2015–2016 and 2017–2018), whereas the spring genotypes Califa Sur and Yecora performed relatively better in the second year (2016–2017) (Figure S4, Supplementary Material). Aragon-03 occupied an intermediate position in the second and third years, with the other landrace, Chamorro, produced the lowest GW in the three seasons. In durum wheat, the modern varieties invariably showed the highest GW values (Avispa in the first and third years, and Don Pedro in the second year), whereas the landraces always had the lowest grain yield. Grain number and grains per spike of bread and durum wheat varieties usually followed the same trend as GW, except for the high GN of Berdun, and the low GS of Aragon-03 and Don Pedro. Aragon-03 had consistently high numbers of tillers and spikes in the three years, which might compensate for its low spike fertility to achieve an intermediate grain number value in some seasons. Modern durum wheat varieties showed the highest TN and SN values in all but the third year, where the intermediate Cocorit and Vitron showed the greatest tillering ability. The landraces Jerez-36 and Senatore Capelli showed generally low tiller and spike numbers but relatively better values in the driest than in the two wetter years. It can be added that less between-genotype differences for GN, GS, TN and SN seemed to exist among the durum wheat varieties analysed than within the set of bread wheat varieties.

Table 3. Mean values of all traits examined in the three-year study.

	Bread Wheat	Durum Wheat
	2015–2016/2016–2017/2017–2018	**2015–2016/2016–2017/2017–2018**
GW (g m^{-2})	316.20 ^{a}/126.66 ^{b}/336.18 ^{a,†}	360.85 ^{a}/136.75 ^{b}/311.28 ^{a}
TN (m^{-2})	533.34 ^{a}/372.48 ^{c}/454.32 ^{b}	369.00 ^{a}/263.64 ^{c}/302.64 ^{b}
SN (m^{-2})	507.48 ^{a}/344.52 ^{b}/421.86 ^{b}	353.16 ^{a}/247.68 ^{b}/288.18 ^{b}
GN (m^{-2})	9383.46 ^{a}/4900.98 ^{b}/8940.84 ^{a}	8535.83 ^{a}/3787.55 ^{b}/6722.21 ^{a}
GS	18.74 ^{b}/13.94 ^{c}/21.00 ^{a}	24.42 ^{a}/15.56 ^{b}/23.77 ^{a}
BW (g m^{-2})	854.64 ^{a}/433.44 ^{b}/798.84 ^{a}	903.96 ^{a}/425.10 ^{b}/737.28 ^{a}
HI	37.19 ^{b}/28.66 ^{c}/43.23 ^{a}	39.41 ^{b}/31.92 ^{c}/41.68 ^{a}
TKW (g)	30.70 ^{b}/24.00 ^{c}/34.00 ^{a}	37.10 ^{b}/31.70 ^{c}/39.80 ^{a}
TW (kg hL^{-2})	75.47 ^{b}/72.77 ^{c}/83.01 ^{a}	79.12 ^{b}/77.11 ^{c}/84.99 ^{a}
PH (cm)	83.94 ^{a}/45.67 ^{b}/77.42 ^{a}	88.28 ^{a}/52.15 ^{c}/79.03 ^{b}
PL (cm)	35.11 ^{a}/12.89 ^{b}/32.08 ^{a}	40.34 ^{a}/17.50 ^{b}/36.44 ^{a}
DH	164.22 ^{b}/144.06 ^{c}/186.61 ^{a}	163.81 ^{b}/141.08 ^{c}/186.11 ^{a}
DM	203.77 ^{b}/174.94 ^{c}/227.23 ^{a}	203.51 ^{b}/175.04 ^{c}/225.73 ^{a}
GF (day)	38.98 ^{a}/30.85 ^{b}/40.52 ^{a}	39.54 ^{a}/33.91 ^{b}/39.63 ^{a}
GFR (mg GDD^{-1})	0.049 ^{a}/0.043 ^{b}/0.051 ^{a}	0.057 ^{a}/0.054 ^{b}/0.059 ^{a}
GPC (%)	10.87 ^{b}/14.13 ^{a}/9.29 ^{c}	9.69 ^{b}/12.69 ^{a}/7.46 ^{c}
SDSS (mm)	72.72 ^{a}/80.61 ^{a}/45.78 ^{b}	42.89 ^{a}/42.99 ^{a}/26.93 ^{b}

† Values within columns followed by different letters are significantly different at $p = 0.05$; GW = Grain weight, TN = Tiller number, SN = Spike number, GN = Grain number, GS = Grains per spike, BW = Biomass weight, HI = Harvest Index, TKW = Thousand kernel weight, TW = Test weight, PH = Plant height, PL = Peduncle length, DH = Days to heading, DM = Days to maturity, GF = Grain filling period, GFR = Grain filling rate, GDD = Growing degree-days, GPC= Grain protein content, SDSS = SDS sedimentation volume.

The bread wheat landrace Aragon-03 produced high biomass in the three years, whereas BW of Marius and Chamorro was relatively increased in the wetter years. In durum wheat, differences among varieties were again less evident, although the landrace Jerez-36 showed higher BW values across the three years and Vitron was the variety that produced less biomass. The spring bread wheat varieties (Califa Sur and Yecora) had significantly high HI values in the three years, which was also observed for the intermediate variety Vitron among durum wheat genotypes. In both wheat crops, the landraces showed the lowest HI values, especially bread wheat Chamorro and durum wheat Senatore Capelli. In general, TKW values decreased in modern cultivars and increased in the landraces and intermediate varieties. It is remarkable the high TKW that found for the durum wheat landrace Jerez-36. Two groups of bread wheat varieties were separated according to TW values: the spring genotypes and the landrace Aragon-03 (higher values), and the winter genotypes and the landrace Chamorro (lower values). In durum wheat, the landraces' kernels had lower TW in the two former years, but TW of Jerez-36 was among the best in the third year.

Differences among varieties were quite consistent for morphology and phenology traits between years (Figure S4, Supplementary Material). In bread or durum wheat, the landraces showed higher PH and PL values than the intermediate and modern breeding varieties. The bread and durum wheat landraces were also invariably later than the breeding cultivars. Nevertheless, significant influence of the growth habit of bread wheat breeding lines on DH and DM was found. Thus, the winter varieties Marius and Berdun were always later that the spring genotypes Yecora and Califa Sur. Additionally, Aragon-03 headed significantly earlier than Chamorro. In general, the landraces of both species had lower GF values in the three-year study. Between-varieties differences for grain filling rates were similar in the first and third year. In bread wheat, the highest, medium and lowest values corresponded to the landraces, and intermediate and modern varieties, respectively. In durum wheat, the landraces and the intermediate variety Vitron showed higher GFR, whereas lower values were obtained for the modern varieties and the intermediate Cocorit. Such trends were not observed in the second year, but the landraces Aragon-03 (bread wheat) and, especially, Jerez-36 (durum wheat) maintained quite high GFR values.

The genotype × year interaction was not statistically significant for GW. However, some genotypes exhibited remarkable differences in grain yield between years (Figure S4, Supplementary Material). To identify the agroclimatic variables with a major effect on yield performance of the genotypes, an AMMI analysis was performed. Since no differences were evident from biplots performed separately for bread and durum wheat varieties, the combined AMMI biplot of the two species was represented (Figure 1). The agroclimatic variables contributing the most to the yield performance of the genotypes in the three years (largest projection over IPCA1) were related to the length of the growing periods and the humidity (TT, Rainfall and RH) in the positive direction, and to heat (Tmax and Tm) in the negative direction. The mean minimum temperatures (Tmin, SA and AM) had the lowest influence on the yield performance across the three years. In agreement with their placement in the AMMI biplot, the second year (2016–2017) was characterised by having high temperatures and low humidity during both growing periods, whereas the third year (2017–2018) had opposite agroclimatic conditions (see Table S1, Supplementary Material). The first year (2015–2016) had an intermediate position, more similar to that of the third year, but with higher Tmin (SA) and lower Tmin (AM).

The location of the bread wheat cultivars in the biplot confirmed that the intermediate variety Marius (winter genotype) performed the best in the third year, whereas the spring genotypes (Yecora and Califa Sur) had the best yield performance in the hottest and driest second year. The landraces Aragon-03 and Chamorro had an intermediate position between these two most contrasting years. Among durum wheat genotypes, Cocorit and Avispa were the best adapted to the wetter environments whereas, the remaining varieties performed relatively better in the second-driest year.

According to the results of the ANOVA tests, the conservation tillage system employed did not seem to affect yield nor most agronomic traits evaluated, only TKW in bread wheat and DM in both species being affected (Table S2, Supplementary Material). However, mean comparisons analyses revealed that, in bread wheat, no-tillage practice significantly increased TKW and GFR, and TW in the third year (Table 4). In durum wheat, higher DM values were observed under no-tillage, whereas minimum tillage increased GFR in the second year and PH in the third year.

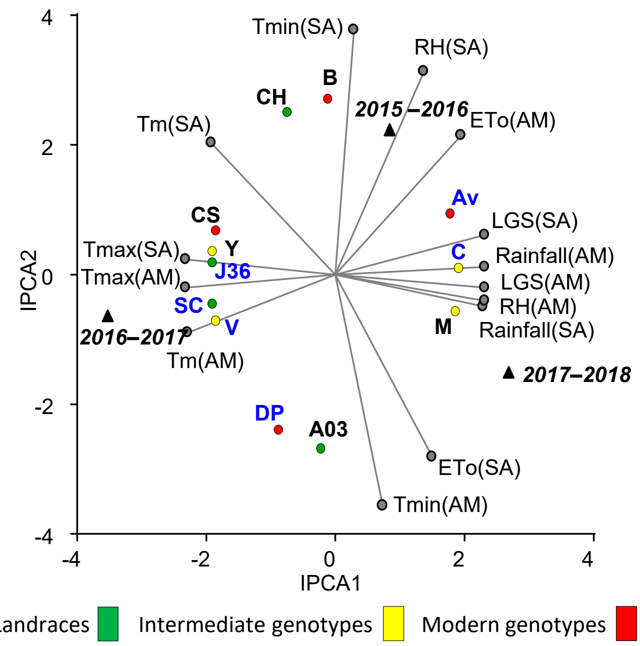

Figure 1. Biplot of the first two axes of the additive main effects and multiplicative interaction (AMMI) model for grain weight in the three environments (i.e., years). In the representation of wheat genotypes, bread and durum wheat varieties are indicated in black and blue lettering, respectively. (Variables: ETo = Reference evapotranspiration, RH = Average daily relative humidity, LGS = length of growing season, Tmin = Mean minimum temperature, Tm= Mean temperature, Tmax= Mean maximum temperature, (SA) = sowing-anthesis period, (AM) = anthesis-maturity period; bread wheat genotypes: A03 = Aragon-03, CH = Chamorro, M = Marius, Y = Yecora, B = Berdun, CS = Califa Sur; durum wheat genotypes: J36 = Jerez-36, SC = Senatore Capelli, C = Cocorit, V = Vitron, Av = Avispa, DP = Don Pedro).

Table 4. Mean values of all traits examined under minimum tillage (MT) and no-tillage (NT) soil management. For those traits with significant interaction between tillage and year, separate values for each year (2015–2016, 2016–2017 and 2017–2018) are shown within brackets.

	Bread Wheat	**Durum Wheat**
	MT/NT	**MT/NT**
GW (g m^{-2})	245.10/274.26	264.58/274.67
TN (m^{-2})	435.66/471.12	304.86/318.66
SN (m^{-2})	411.66/437.58	288.00/304.68
GN (m^{-2})	7619.46/7864.02	6055.11/5969.70
GS	18.22/17.57	21.43/20.23
BW (g m^{-2})	669.18/722.04	682.68/694.92
HI	35.67/37.05	37.59/37.26
TKW (g)	28.70 ^{b}/30.40 ^{a,†}	36.70/35.70
TW (kg hL^{-2})	(75.16/75.78) (72.72/72.96) (84.61 ^{a}/81.42 ^{b})	80.13/80.69
PH (cm)	(82.80/85.08) (42.89/48.46) (78.61/76.22)	(89.20/87.36) (49.62/54.68) (82.61 ^{a}/75.44 ^{b})
PL (cm)	26.01/27.38	(40.27/40.41) (16.09/18.91) (38.17/34.72)
DH	164.98/164.94	(163.33/164.28) (141.56/140.61) (185.56/186.67)
DM	(203.78/203.78) (174.89/175.22) (226.17/228.39)	199.88b/200.81 ^{a}
GF (day)	36.00/37.06	(40.17/39.28) (33.00/35.00) (39.33/40.00)
GFR (mg GDD^{-1})	0.046 ^{b}/0.049 ^{a}	(0.057/0.058) (0.056 ^{a}/0.052 ^{b}) (0.057/0.062)
GPC (%)	11.51/11.35	10.08/9.81
SDSS (mm)	66.36/66.38	37.82/37.38

† Values within columns followed by different letters are significantly different at $p = 0.05$; GW = Grain weight, TN = Tiller number, SN = Spike number, GN = Grain number, GS = Grains per spike, BW = Biomass weight, HI = Harvest Index, TKW = Thousand kernel weight, TW = Test weight, PH = Plant height, PL = Peduncle length, DH = Days to heading, DM = Days to maturity, GF = Grain filling period, GFR = Grain filling rate, GDD = Growing degree-days, GPC= Grain protein content, SDSS = SDS sedimentation volume.

For those traits showing significant genotype × tillage interaction (Table S2, Supplementary Material), further mean comparison analyses considering variety and tillage system were done (Figure 2). Overall, GFR was the trait for which more varieties showed a significant influence of the tillage system, the effect seeming to be dependent on the environment conditions. Higher GFR values were mostly obtained under no-tillage in wetter years, whereas minimum tillage seemed to be more beneficial during the extremely driest, second year. Nevertheless, this trend could not be generalized for all the varieties examined (i.e., see Yecora in 2016–2017). No-tillage had also a significant positive effect on SN, GN, GS, PH and/or PL in some bread wheat genotypes during one of the wetter years. In the case of durum wheat varieties, and limited to the first year, significant increasing values of TN under no-tillage were also detected for Senatore Capelli, while SN of the other landrace, Jerez-36, was positively influenced by minimum tillage. It is remarkable that GFR was the only trait for which significant differences depending on the tillage treatments were detected in the driest year. It agreed with the finding that the effect of genotype × tillage interaction on data recorded in 2016–2017 was only significant for this trait (Table S2, Supplementary Material).

Given that the environment strongly affected the agronomic variables examined, multivariate PCA analysis was used to determine the relations among these traits in the two most contrasting environments, the driest second year (2016–2017) and the wettest third year (2017–2018), under each of the conservation tillage systems tested. The first two axes of the PCAs accounted for 73% to 84% of the total variance, indicating that most of the information contained in those two seasons' data could be summarized by projecting the points on the plane that these axes determined (Figure 3).

Overall, GN was the trait most closely related with crop yield (GW) independent of the year considered and under any of the two conservation tillage systems.

In bread wheat, the relation between yield and the remaining variables under minimum tillage was quite similar in the two analysed years, GW being positively correlated with yield components GS and HI, and negatively correlated with DH and DM. Only for BW it was found that the positive relation with GW was restricted to the driest season (2016–2017). Relevant differences between years were observed, however, under no-tillage. The same trends as noted for minimum tillage were observed in 2016–2017. However, in the wettest year, GW appeared closely associated with SN and TN, whereas it was unrelated to HI and the phenology traits. The position of the bread wheat varieties in the biplot spaces obtained for the driest year showed that the earliest spring varieties, Califa Sur and Yecora, had high PC1 values (related to lower DH and DM, and higher GW), regardless of the tillage system. Among the remaining varieties, Aragon-03 and Marius performed better under no-tillage, while the opposite was observed for Chamorro and Berdun. In the wetter year, grain yield of the landraces and the intermediate variety Marius improved under no-tillage, whereas the modern varieties and Yecora were placed closer to GW under minimum tillage.

In durum wheat, the relation between yield and the remaining traits remained quite similar regardless of the tillage system and the year under study. In general terms, GW was positively correlated with HI and GS, while negatively correlated with DH and DM. Only under no-tillage, some relevant differences were detected between years for TN and SN, which occupied opposite positions along the PC2 axe in 2016–2017 and 2017–2018, and for TKW (inversely related with GW in the wetter year). The traditional varieties were always placed apart from the improved varieties. These were separated by the PC2, which was mostly associated with tillering ability and biomass development.

The yield stability of the genotypes was assessed by Wricke's ecovalence method (Table 5). The analysis was separately conducted for GW values recorded across the three-year study in no-tillage and minimum tillage plots. For all the varieties tested, lower ecovalence values, and therefore higher stability, were generally obtained under minimum tillage. Among bread wheat genotypes, landraces had usually lower ecovalence values, especially Chamorro, although no clear effect of breeding intensity was detected. The winter variety Marius and the spring variety Califa Sur were invariably the least stable, evidencing that yield stability was not influenced by growth habit. The relative stability of some durum wheat genotypes seemed to be dependent on the tillage system. Thus, landrace Jerez-36 was the most stable under minimum tillage but quite unstable under no-tillage, while the opposite trend was found for Vitron. The high-yielding variety Avispa and the traditional Senatore Capelli were unstable with all of the tillage treatments.

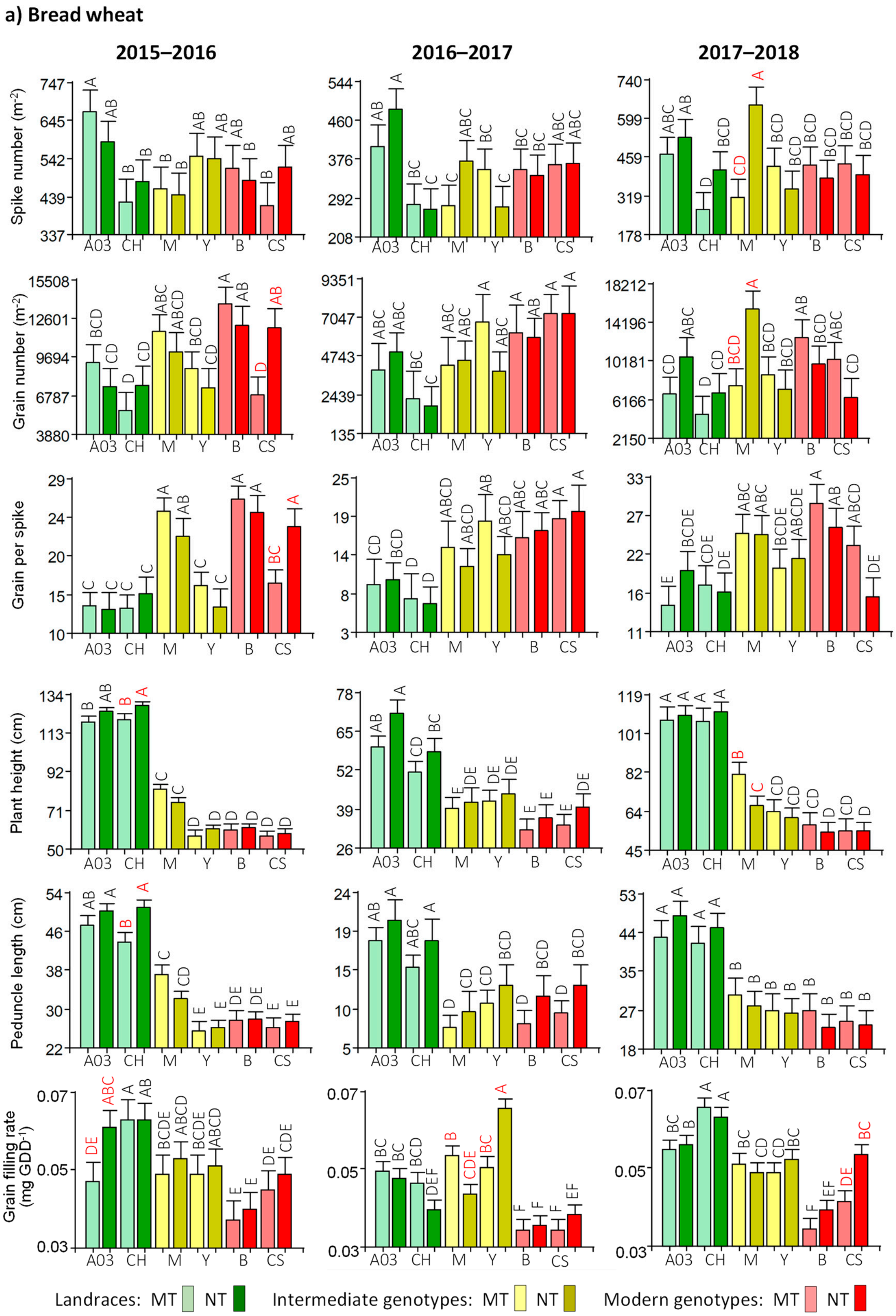

Figure 2. *Cont.*

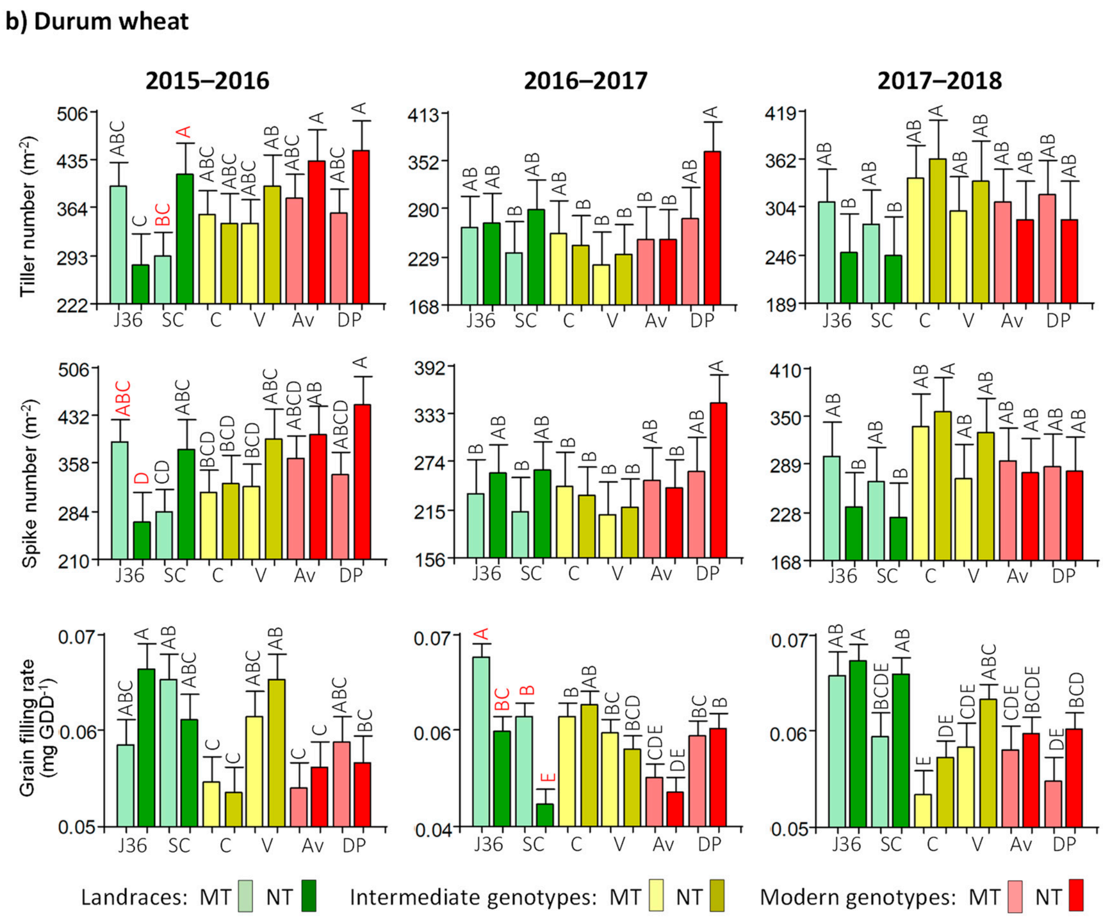

Figure 2. Mean values of the traits with significant genotype × tillage effect on any of the three years of the study for (**a**) bread wheat and (**b**) durum wheat. Means with different letters are significantly different at $p = 0.05$. The letters are highlighted in red for varieties that show significant differences between mean values in the two tillage systems. (Tillage systems: MT = Minimum tillage, NT = No-tillage; bread wheat genotypes: A03 = Aragon-03, CH = Chamorro, M = Marius, Y = Yecora, B = Berdun, CS = Califa Sur; durum wheat genotypes: J36 = Jerez-36, SC = Senatore Capelli, C = Cocorit, V = Vitron, Av = Avispa, DP = Don Pedro).

Table 5. Wricke's ecovalence values of grain yield for the wheat genotypes in the three-year study. Grain wheat values obtained in no-tillage (NT) and minimum tillage (MT) plots have been analysed, pooled (NT + MT) and separately.

	MT		NT		NT + MT	
Wheat Species	**Wi Value**	**Genotype**	**Wi Value**	**Genotype**	**Wi Value**	**Genotype**
Bread wheat	285	Yecora	958	Chamorro	223	Chamorro
	541	Aragon-03	2998	Berdun	735	Berdun
	619	Chamorro	3695	Yecora	1348	Aragon-03
	1651	Berdun	6296	Aragon-03	1498	Yecora
	5990	Marius	22481	Califa Sur	2529	Califa Sur
	9168	Califa Sur	39046	Marius	10122	Marius
Durum wheat	271	Jerez-36	732	Vitron	42	Vitron
	462	Don Pedro	1354	Cocorit	467	Jerez-36
	834	Cocorit	2271	Don Pedro	519	Cocorit
	1249	Vitron	2895	Senatore Capelli	651	Don Pedro
	3217	Senatore Capelli	3375	Jerez-36	2874	Senatore Capelli
	4052	Avispa	9110	Avispa	5615	Avispa

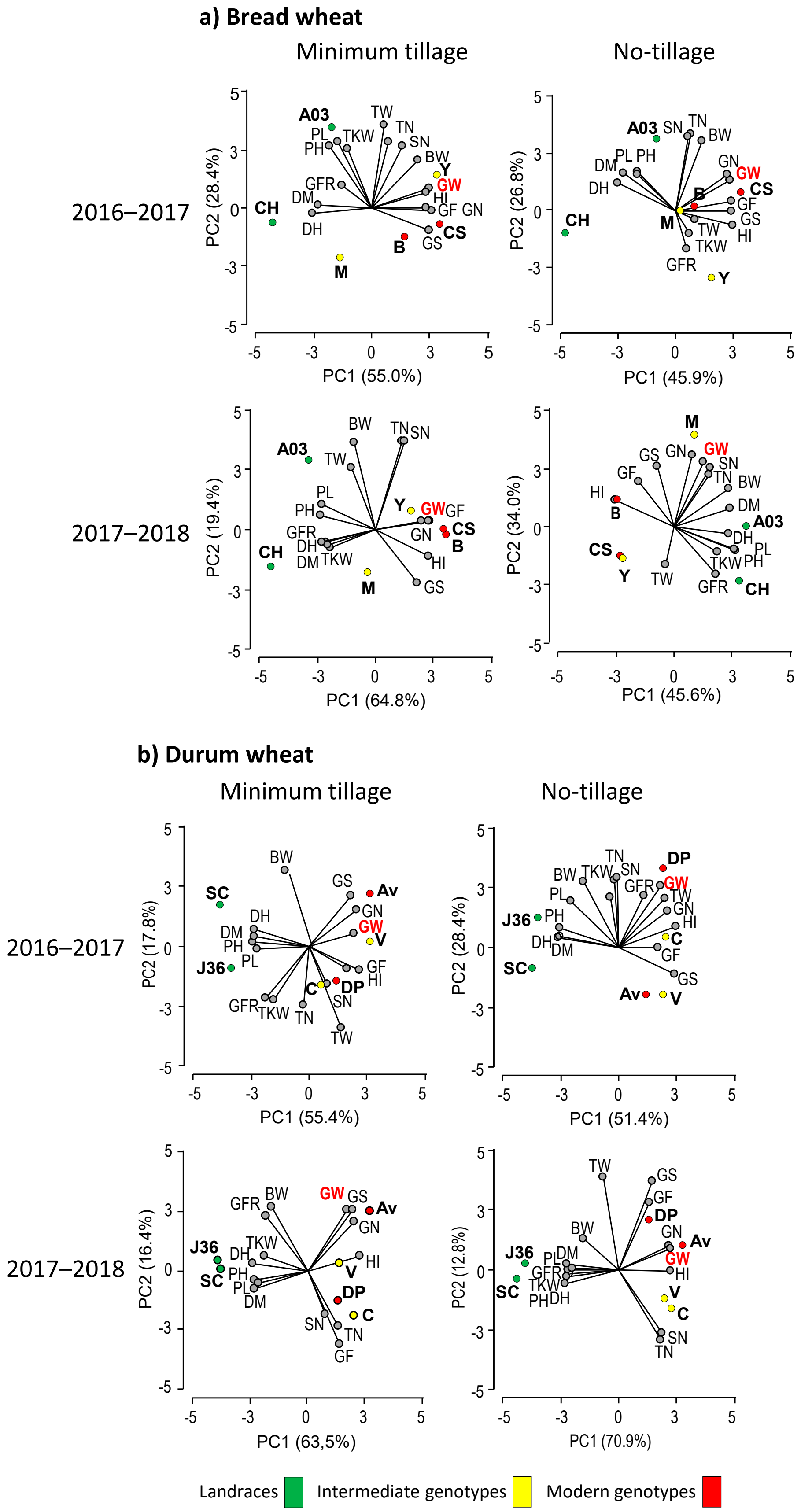

Figure 3. Biplot of the first two axes of the principal component analysis summarizing the relationships between grain weight (GW, highlighted in red) and the agronomic traits in the two more contrasting

seasons (2016–2017 and 2017–2018) under minimum tillage and no-tillage in (**a**) bread wheat and (**b**) durum wheat. (Variables: TN = Tiller number, SN = Spike number, GN = Grain number, GS = Number of grains per spike, BW = Biomass weight, HI = Harvest index, TKW = Thousand kernel weight, TW = Test weight, DH = Days to heading, DM = Days to maturity, GF = Grain filling period, GFR = Grain filling rate, PH = Plant height, PL = Peduncle length; bread wheat genotypes: A03 = Aragon-03, CH = Chamorro, M = Marius, Y = Yecora, B = Berdun, CS = Califa Sur; durum wheat genotypes: J36 = Jerez-36, SC = Senatore Capelli, C = Cocorit, V = Vitron, Av = Avispa, DP = Don Pedro).

An alternative approach was followed to compare the yield stability among genotypes. The grain yield reduction of each variety with respect to the GW value of the best yielding genotype was calculated for the two more contrasting years, 2016–2017 and 2017–2018, and represented in scatter plots (Figure 4). The closer to the diagonal a genotype is placed in the scatter plot, the less its relative yield is affected by environmental changes. For this analysis, the bread and durum wheat reference varieties under minimum tillage were, respectively, Califa Sur and Avispa in 2016–2017, and Yecora and Vitron in 2017–2018. Under no-tillage, the reference varieties were Marius and Avispa in 2016–2017, and Califa Sur and Don Pedro in 2017–2018.

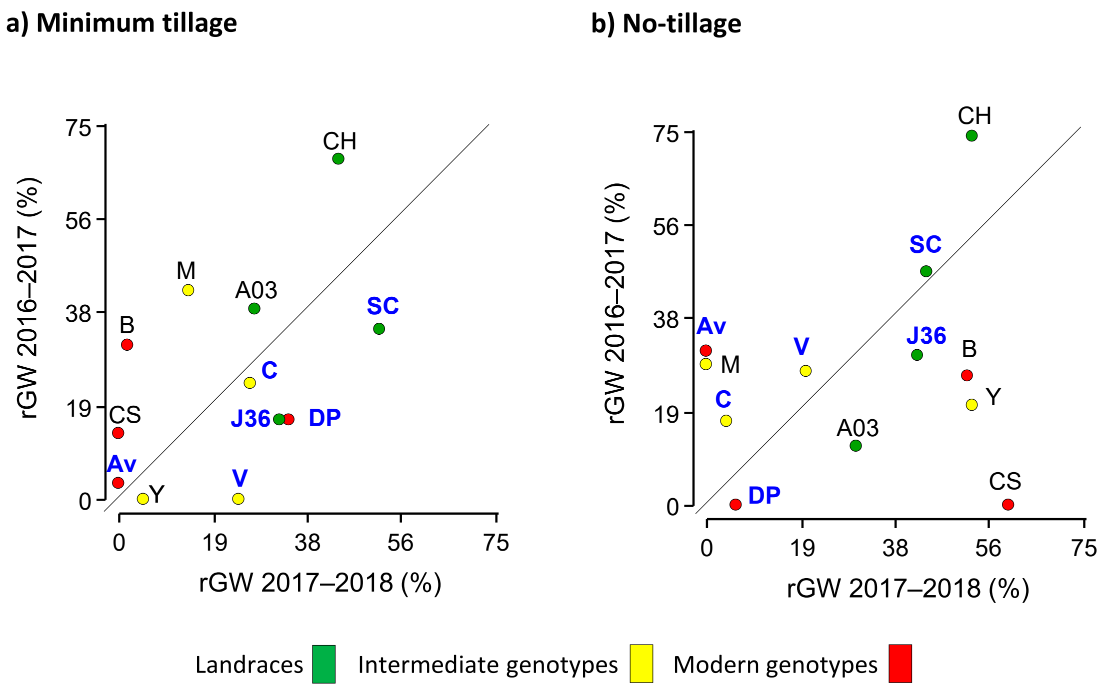

Figure 4. Relationship between the relative grain yield (rGW) of each wheat genotype in the two most contrasting seasons under (**a**) minimum tillage and (**b**) no-tillage. Relative yield values are calculated, as percentage, respect to the best yielding genotype. In the representation of wheat genotypes, bread and durum wheat varieties are indicated in black and blue lettering, respectively. (Bread wheat genotypes: A03 = Aragon-03, CH = Chamorro, M = Marius, Y = Yecora, B = Berdun, CS = Califa Sur; durum wheat genotypes: J36 = Jerez-36, SC = Senatore Capelli, C = Cocorit, V = Vitron, Av = Avispa, DP = Don Pedro).

Overall, the bread wheat varieties were less stable under no-tillage. The spring varieties Califa Sur and Yecora were the most stable under minimum tillage, but very unstable under no-tillage. The landrace Aragon-03 was among the most stable genotypes whatever tillage system used. In general, the relative stability of durum wheat varieties was less dependent on the tillage system. However, Avispa and Vitrón were more stable under minimum tillage and no-tillage, respectively. These results, based on GW data from the wettest and driest years, were broadly in agreement with data for the whole set of observations obtained in the three-year experiment by the ecovalence method (Table 5).

3.3. Technological Quality

The ANOVA test indicated that the quality traits were significantly affected by year, genotype and genotype × year interaction in the two species, while the tillage system and interactions of tillage with year and with genotype did not have any relevant effect (Table S2).

The highest GPC values were obtained in 2016–2017, whereas the lowest contents were found in 2017–2018, either in bread or durum wheat genotypes (Table 3), which supported an inverse influence of the environment on GPC and GW. Correlation analyses performed separately for varieties within each breeding period detected a significant negative correlation between GPC and GW, except for the landraces of durum wheat. However, when the analyses were performed for each of the years of study, the correlation was only significant (and negative) for bread wheat in 2015–2016 (Table S3). The landraces of both species had higher protein content than modern and intermediate genotypes (Figure S4, Supplementary Material), which could also be related to their generalized low yield.

The average SDSS values were significantly lower in the rainiest third year than in the first and second years (Table 3). Among the bread wheat varieties, Chamorro and Yecora had the best quality performance across the study (Figure S4, Supplementary Material). The modern varieties Califa Sur and Berdun suffered greater penalties in the first and third wetter year, while Marius and Aragon-03 invariably showed the lowest SDSS values. In durum wheat, the old genotype Jerez-36 showed the best SDSS values in the three years, the modern variety Don Pedro performing the worst. A significant positive correlation between GPC and SDSS was detected for varieties within each breeding period, except for the intermediate varieties of bread wheat ($p = 0.056$). Separate analyses for each year revealed significant positive correlations in the first year for both species and in the third year for durum wheat varieties, whereas no correlation between GPC and SDSS was detected in the driest season's analyses (Table S3).

The electrophoretic analyses indicated that the bread wheat varieties had different allelic composition for the HMW-GS loci. For the *Glu-D1* locus, main genetic determinant of bread wheat rheological properties, Califa Sur and Yecora expressed subunits 5 + 10, Marius and Chamorro expressed subunits 4 + 12, and Berdun and Aragon-03 expressed subunits 2 + 12. In durum wheat, the analyses of the LMW-GS revealed that all the genotypes possessed the alleles *Glu-A3j* (subunit 6), *Glu-B3r* (subunits 2 + 4 + 15 + 19) and *Glu-B2a* (subunit 12). Higher variability was observed for the HMW-GS, although all the varieties except one possessed the null allele at *Glu-A1*, and only three alleles were detected at the highly variable *Glu-B1* locus (Figure S5).

4. Discussion

The next generation of crop cultivars will have to satisfactorily respond to the main concerns of current agroecosystems: increasing food demand, soil degradation, overuse of inputs and climate uncertainty. In the case of wheat, functional quality requirements must also be kept in mind. Our study evaluated the yield and quality performance of a set of bread and durum wheat varieties under two sustainable soil tillage systems. The panel of genotypes included representatives of traditional and improved varieties to identify particular traits for which old materials can aid the genetic improvement of higher-yielding cultivars developed for intensive, high-input agriculture systems.

4.1. Overall Varieties' Performance under Conservation Soil Management

The climatic conditions during the field trial experiment were quite typical of dry regions of Spain, characterised by erratic amounts and distribution of rainfall [39]. Even in the rainiest season (2017–2018), rainfall was within the range of a semi-arid climate (e.g., [40,41]). It surely implies that the plant-growing periods were always under some degree of drought stress, from moderate to severe, which might be the future climate scenario in many template zones that have traditionally received adequate water input [41].

All the traits examined were significantly influenced by the environment. The most important agroclimatic variables affecting genotype adaptation to the environment, in terms of grain yield (i.e., GW), were temperature (daily mean and maximum), rainfall, and length of the cycle expressed as thermal time (Figure 1). No significant differences in GW between the first (2015–2016) and third (2017–2018) years were detected in any of the two species, probably due to adequate water input during the reproductive period and grain filling stage (from March to May) [38]. In contrast, the extremely drought environment in the second year (2016–2017) greatly penalised grain yield and yield components (Table 3). The water deficit also reduced the growth cycle (DH, DM and GF) and decreased the daily rates of translocation of carbohydrate reserves from vegetative organs to the grain (GFR), which is in agreement with lower TKW values, as reported here and in other studies [42,43]. These results confirmed the already contrasted role of the amount and distribution of rainfall during the growth period in wheat yield under Mediterranean rainfed conditions [43–45].

With the exception of Aragon-03, landraces were always the genotypes with the lowest grain yields. This reflects the improved partitioning of assimilates to the grain that provoked the introduction of dwarfing alleles in wheat cultivars [46]. However, the relative yield performance of each commercial, breeding-derived cultivar varied depending on the year. Among the modern and intermediate varieties of bread wheat, grain yield in response to the different environmental conditions was associated with growth habit, which is in agreement with Sanchez-Garcia et al. [45]. Under severe water stress, the earliest spring varieties performed relatively better than the winter varieties, whereas the latter had the best grain yields in more humid environments. The landrace Aragon-03 behaved acceptably well across the environments, with yield decrements of 20–25% respect to the best performing variety at any of the trial seasons (see Figure 1 and Figure S4). Chamorro behaved also as very stable based on the ecovalence values, but this landrace showed the lowest yield among all the varieties tested. As confirmed in our study, Aragon-03 is characterized by high tillering and spike number, which may compensate for the low spike fertility inherent to landraces. It can be noted that this old genotype, selected from a Spanish landrace before 1940, was the leading variety in Spain during the period 1960–1976 due to its wide adaptation to drought and cool environments [47].

In durum wheat, the tested varieties showed less overall differences in yield stability than in bread wheat. The high stability of the intermediate genotypes and the finding that the landraces performed relatively better during the driest and hottest year concurred with findings reported by Subira and co-workers [25]. These authors suggested that Senatore Capelli has a good adaptation to drought stresses, which agrees with its lowest score for IPCA1, strongly related to rainfall. However, the Spanish landrace Jerez-36 showed better yield performance and stability, with yield loss rates clearly lower than those of Senatore Capelli (17–37% for Jerez-36; 36–46% for Senatore Capelli). Its higher GFR and TKW values, especially in the driest environment, support the fact that Jerez-36 has a greater water use efficiency during grain filling, thus resulting in heavy grain formation.

The presence of dwarfing alleles in varieties released from the Green Revolution times has been associated with physiological changes leading to superior number of grains rather than with changes in individual kernel weight [48]. TKW has indeed been included among the traits for which landraces can provide genetic diversity that may contribute to improved yields in rainfed agroecosystems, where heavier kernels may compensate for lower spike fertility [49,50]. The direct physiological relation between grain filling rate and weight provides another target trait for adaptation to lower input wheat cropping (e.g., [51,52]). The landraces examined here have generally showed the greatest GFR values, especially under moderate water scarcity. Furthermore, even in the driest season, GFR of bread wheat Aragon-03 and durum wheat Jerez-36 have been significantly higher that that found in modern cultivars.

Crop biomass is another interesting trait in the context of non-conventional management agro-systems. Decreased biomass and the subsequent reduced ability to compete against weeds represents a problematic issue in conservation agriculture, where weed pressure can adversely affect crop yield, mainly in the long term (e.g., [53]). On the other hand, unharvested crop residues contribute to generate above-ground and below-ground biomass, whose decomposition and recirculation substantially enhances soil quality. It can be noted that soil organic matter constitutes a store of nutrients and water, and controls the common erosive processes, its low level in dryland representing an important vulnerability factor for the sustainability of Mediterranean agriculture [54,55]. Additionally, increased aerial and root biomass contribute to improve wheat plant's ability to capture resources and can lead to a greater ground cover, reducing soil temperature and water lost by evaporation. All these beneficial effects of plant biomass under conservation agriculture systems are, however, constrained when the crop cultivar shows a genotype-dependent limited vegetative growth. The higher biomass production that characterizes landraces (this study; [1,56,57]) not only helps crop plants compete better with weeds, thus reducing herbicide applications, but also enhances the quality of degraded rainfed soils, clearly being advantageous for sustainable agroecosystems [1,58]. Among the landraces examined in the study, Aragon-03 and Jerez-36 can again be highlighted as good genotypes under either moderate or severe dry conditions. In the case of Aragon-03, it might be related to the remarkable tillering ability that characterizes this old bread wheat genotype.

As already noted for yield and agronomic traits, technological quality parameters were also greatly affected by climatic conditions. Some yield diluting effect is surely on the basis of both, the straight inverse relation between GPC and annual rainfall [59], and the higher GPC values obtained in the usually lower yielding landraces. Aragon-03 is indeed the only genotype among all examined that presented high GPC and acceptable grain yield. The SDSS values decreased significantly in the rainiest year. The remarkable reduction observed in durum wheat flour (Table 3) was probably influenced by the extremely low protein content, known to have a deleterious effect on wheat rheological properties [60]. No relation with the period of release was detected for gluten strength, as estimated by the SDSS test. It is well known that this quality trait has a remarkable genotype influence. In the case of bread wheat, the HMW-GS encoded by the *Glu-D1* locus are the main genetic determinants of gluten quality [61,62]. This explains the consistently higher SDSS values of Yecora, intermediate of Berdun, and lower of Aragon-03 and Marius, associated with the presence of the subunits 5 + 10 (good quality), 2 + 12 (medium quality) and 4 + 12 (bad quality), respectively [61–63]. The good values of Chamorro are inconsistent with its glutenin composition (4 + 12 *Glu-D1* subunits) but were not unexpected. This traditional variety, largely appreciated by its bread-making quality, is currently being used in the elaboration of artisanal baking products [64]. In durum wheat, all the varieties had the same allelic combination for LMW-GS, the most relevant prolamins for gluten quality. The worse values of Senatore Capelli, Don Pedro and Cocorit can be due to the negative effect on gluten strength of HMW-GS 20x + 20y encoded by the *Glu-B1* locus [65].

4.2. Minimum Tillage versus No-Tillage

The results discussed above refer to the average behaviour of the varieties under any of the two non-conventional tillage systems tested. However, our study has revealed some differences between soil conservation management practices regarding varieties' performance and stability as well as on the relevance of some particular traits (i.e., TKW and GFR) for improved grain yields. Grain yield itself was not significantly affected by tillage management, although some positive effect of no-tillage was evidenced on GW and most yield-related traits, especially in bread wheat (Table 4). This could be related to the overall beneficial effect of no-tillage over reduced tillage on soil components (especially, for $N\text{-}NO_3^-$ and P), saturation time and water infiltration. These observations are in agreement with other studies that have reported significant increases in soil N or water content under no-tillage [4,7,9,10]. Some modifications of soil properties might be associated not merely with the reduced breakdown of macro-aggregates but also with the slower decomposition of crop residues when no-tillage is practiced [6,9,66].

Earlier results on the differential effects of conservation tillage practices on wheat yield are quite controversial. Some studies have reported a positive effect of no-tillage [7,12,67], whereas others have found negative effects [9,68] or no significant differences between both systems [69,70]. It must be noted that only the studies of Khorami et al. [9] and Carr et al. [70] were based on the analysis of more than one genotype (4 and 5, respectively) in different environments. Comparison of the mean GW values obtained for each variety under minimum tillage and no-tillage reveals different trends among the genotypes tested in the present study (Figure 5). Furthermore, significant genotype × tillage treatment interactions were detected for some relevant yield-related traits in less severe drought conditions (Table S2, Supplementary Material). Therefore, not only the specific varieties analysed but also the different climatic conditions that affected the field trials conducted might well explain such disparate conclusions.

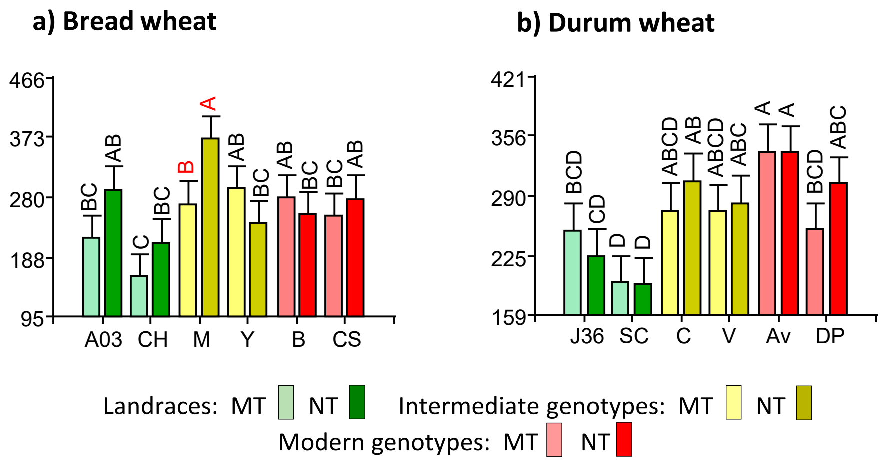

Figure 5. Mean values of grain weight under minimum tillage and no-tillage for (**a**) bread wheat and (**b**) durum wheat genotypes. Means with different letters are significantly different at $p = 0.05$. The letters are highlighted in red for varieties that show significant differences between mean values in the two tillage systems. (Tillage systems: MT = Minimum tillage, NT = No-tillage; bread wheat genotypes: A03 = Aragon-03, CH = Chamorro, M = Marius, Y = Yecora, B = Berdun, CS = Califa Sur; durum wheat genotypes: J36 = Jerez-36, SC = Senatore Capelli, C = Cocorit, V = Vitron, Av = Avispa, DP = Don Pedro.)

Yield stability of bread wheat genotypes was markedly higher when reduced tillage was practised (Table 5; Figure 4), which was in agreement with the conserved position of the varieties on the planes determined by the PCA axes (Figure 3a, minimum tillage). This is likely linked with the finding that the relation between GW and relevant yield-related and adaptive traits, like HI and precocity, may differ under no-tillage depending on the climate conditions, whereas remains quite constant under minimum tillage across the environments (Figure 3a). A similar though less marked trend of higher stability under minimum tillage has been found in durum wheat, where tillering ability and TKW were the traits whose relation with yield differed between years under no-tillage.

Honsdorf and co-workers determined the effects of genotype, tillage, and genotype × tillage interactions on yield performance of a panel of bread and durum wheat genotypes, all of them developed by CIMMYT and released after 1964 [71]. The materials were cultivated on raised beds under different tillage systems (conventional soil management and no-tillage) and water regimes (full and reduced irrigation). The results of that study cannot be directly compared with the results found here because of the different experimental conditions and materials assayed. Nevertheless, these authors also found that genotype × tillage interactions were more frequent under wetter conditions, and more relevant in bread wheat than in durum wheat. One reason adduced for this latter finding was because the group of bread wheat varieties analyzed might have comprised a larger genetic variation than the durum wheat genotypes. This might also hold for the differences found in the present study between bread and durum wheat regarding not only yield stability but also the interactions of genotypes with either tillage systems and environment conditions.

5. Conclusions

The present study has provided some relevant clues that may be of help for wheat varietal choice when conservation tillage practices are implemented in drought-prone zones. All the old varieties examined, except bread wheat cultivar Aragon-03, have shown too low yields to be competitive in terms of crop productivity. However, their advantages over commercial varieties have been described for some yield-related traits that have been identified as potential targets to achieve better grain yields under soil conservation management such as TKW, GFR, biomass production and tillering ability [11]. The high variability for these traits reported in Mediterranean landraces (e.g., [1,15,16]) supports the potential of landraces to improve variety adaptation to conservation agriculture. Further research is then strongly recommended to evaluate more diversified landrace in order to select the most adapted to sustainable agriculture practices under different environments. No significant influence of tillage management, tillage × environment, or genotype × tillage management has been detected for GPC or SDSS values. This makes it possible to assume that wheat quality of any variety eventually selected will be unaffected whatever the conservation tillage practice utilized.

Supplementary Materials: The following are available online at http://www.mdpi.com/2071-1050/11/17/4522/s1, Table S1: Values of agroclimatic variables for SA and AM growing periods, Table S2: Results of ANOVAs tests for all variables examined, Table S3: Correlation coefficients between GPC and GW, and between GPC and SDSS, Figure S1: Monthly rainfall, mean Tmax and mean Tmin during the three years of study, Figure S2: Images of MT and NT plots, Figure S3: Water infiltration rate and saturation time in the crop and fallow plots, Figure S4: Mean comparison of all traits between genotypes per year of study, Figure S5: Electrophoretic profiles of HMW-GS and LMW-GS in all varieties.

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References

1. Carranza-Gallego, G.; Guzmán, G.; Soto, D.; Aguilera, E.; Villa, I.; Infante-Amate, J.; Herrera, A.; González de Molina, M. Modern Wheat Varieties as a Driver of the Degradation of Spanish Rainfed Mediterranean Agroecosystems throughout the 20th Century. *Sustainability* **2018**, *10*, 3724. [CrossRef]
2. Gonzalez-Sanchez, E.; Veroz-Gonzalez, O.; Blanco-Roldan, G.; Marquez-Garcia, F.; Carbonell-Bojollo, R. A renewed view of conservation agriculture and its evolution over the last decade in Spain. *Soil Tillage Res.* **2015**, *146*, 204–212. [CrossRef]
3. Giraldo, P.; Benavente, E.; Manzano-Agugliaro, F.; Gimenez, E. Worldwide Research Trends on Wheat and Barley: A Bibliometric Comparative Analysis. *Agronomy* **2019**, *9*, 352. [CrossRef]
4. Ghaley, B.; Rusu, T.; Sandén, T.; Spiegel, H.; Menta, C.; Visioli, G.; O'Sullivan, L.; Gattin, I.; Delgado, A.; Liebig, M. Assessment of benefits of conservation agriculture on soil functions in arable production systems in Europe. *Sustainability* **2018**, *10*, 794. [CrossRef]
5. Murillo, J.; Moreno, F.; Girón, I.; Oblitas, M. Conservation tillage: Long term effect on soil and crops under rainfed conditions in south-west Spain (Western Andalusia). *Span. J. Agric. Res.* **2004**, *2*, 35–43. [CrossRef]
6. Sombrero, A.; De Benito, A. Carbon accumulation in soil. Ten-year study of conservation tillage and crop rotation in a semi-arid area of Castile-Leon, Spain. *Soil Tillage Res.* **2010**, *107*, 64–70. [CrossRef]
7. Santín-Montanyá, M.; Fernández-Getino, A.; Zambrana, E.; Tenorio, J. Effects of tillage on winter wheat production in Mediterranean dryland fields. *Arid Land Res. Manag.* **2017**, *31*, 269–282. [CrossRef]
8. Pittelkow, C.M.; Liang, X.; Linquist, B.A.; Van Groenigen, K.J.; Lee, J.; Lundy, M.E.; Van Gestel, N.; Six, J.; Venterea, R.T.; van Kessel, C. Productivity limits and potentials of the principles of conservation agriculture. *Nature* **2015**, *517*, 365–368. [CrossRef]

9. Khorami, S.; Kazemeini, S.; Afzalinia, S.; Gathala, M. Changes in soil properties and productivity under different tillage practices and wheat genotypes: A short-term study in Iran. *Sustainability* **2018**, *10*, 3273. [CrossRef]
10. Lampurlanés, J.; Plaza-Bonilla, D.; Álvaro-Fuentes, J.; Cantero-Martínez, C. Long-term analysis of soil water conservation and crop yield under different tillage systems in Mediterranean rainfed conditions. *Field Crops Res.* **2016**, *189*, 59–67. [CrossRef]
11. Herrera, J.; Verhulst, N.; Trethowan, R.; Stamp, P.; Govaerts, B. Insights into genotype× tillage interaction effects on the grain yield of wheat and maize. *Crop Sci.* **2013**, *53*, 1845–1859. [CrossRef]
12. Taner, A.; Arisoy, R.Z.; Kaya, Y.; Gultekin, I.; Partigoc, F. The effects of various tillage systems on grain yield, quality parameters and energy indices in winter wheat production under the rainfed conditions. *Fresenius Environ. Bull.* **2015**, *24*, 1463–1473.
13. Ficiciyan, A.; Loos, J.; Sievers-Glotzbach, S.; Tscharntke, T. More than yield: Ecosystem services of traditional versus modern crop varieties revisited. *Sustainability* **2018**, *10*, 2834. [CrossRef]
14. Newton, A.; Akar, T.; Baresel, J.; Bebeli, P.; Bettencourt, E.; Bladenopoulos, K.; Czembor, J.; Fasoula, D.; Katsiotis, A.; Koutis, K. Cereal landraces for sustainable agriculture. A review. *Agron. Sustain. Dev.* **2010**, *30*, 237–269. [CrossRef]
15. Moragues, M.; del Moral, L.F.G.; Moralejo, M.; Royo, C. Yield formation strategies of durum wheat landraces with distinct pattern of dispersal within the Mediterranean basin I: Yield components. *Field Crops Res.* **2006**, *95*, 194–205. [CrossRef]
16. Ruiz, M.; Giraldo, P.; Royo, C.; Villegas, D.; Aranzana, M.J.; Carrillo, J.M. Diversity and Genetic Structure of a Collection of Spanish Durum Wheat Landraces. *Crop Sci.* **2012**, *52*, 2262–2275. [CrossRef]
17. Kyzeridis, N.; Biesantz, A.; Limberg, P. Comparative trials with durum-wheat landraces and cultivars in different ecological environments in the Mediterranean region. *J. Agron. Crop Sci.* **1995**, *174*, 133–144. [CrossRef]
18. Talas, F.; Longin, F.; Miedaner, T. Sources of resistance to Fusarium head blight within Syrian durum wheat landraces. *Plant Breed.* **2011**, *130*, 398–400. [CrossRef]
19. Srivastava, J.; Damania, A. Use of collections in cereal improvement in semi-arid areas. In *The Use of Plant Genetic Resources*; Brown, A.H.D., Frankel, O.H., Marshall, D.R., Williams, J.T., Eds.; Cambridge University Press: Cambridge, UK, 1989; pp. 88–104.
20. Ruiz, M.; Aguiriano, E.; Carrillo, J. Effects of N fertilization on yield for low-input production in Spanish wheat landraces (*Triticum turgidum* L. and *Triticum monococcum* L.). *Plant Breed.* **2008**, *127*, 20–23. [CrossRef]
21. Carranza-Gallego, G.; Guzman, G.; Garcia-Ruiz, R.; de Molina, M.G.; Aguilera, E. Contribution of old wheat varieties to climate change mitigation under contrasting managements and rainfed Mediterranean conditions. *J. Clean. Prod.* **2018**, *195*, 111–121. [CrossRef]
22. Genetic Resources Information System for Wheat and Triticale. Available online: http://www.wheatpedigree.net/ (accessed on 22 July 2019).
23. Spanish Variety Register Catalogue. Available online: https://www.mapa.gob.es/app/regVar/BusRegVar.aspx?id=es (accessed on 22 July 2019).
24. Zadoks, J.C.; Chang, T.T.; Konzak, C.F. A decimal code for the growth stages of cereals. *Weed Res.* **1974**, *14*, 415–421. [CrossRef]
25. Subira, J.; Álvaro, F.; del Moral, L.F.G.; Royo, C. Breeding effects on the cultivar× environment interaction of durum wheat yield. *Eur. J. Agron.* **2015**, *68*, 78–88. [CrossRef]
26. Allen, R.G.; Pereira, L.S.; Raes, D.; Smith, M. *Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56*; FAO: Rome, Italy, 1998; pp. 3–8.
27. Payero, J. Introducction to growing degree days. In *Agronomic Crops*; Clemson University: Clemson, SC, USA, 2017.
28. Pask, A.; Pietragalla, J.; Mullan, D.; Reynolds, M. *Physiological Breeding II: A Field Guide to Wheat Phenotyping*; Pask, A., Pietragalla, J., Mullan, D., Reynolds, M., Eds.; CIMMYT: México D.F., Mexico, 2012; pp. 72–77.
29. Bremner, J. Nitrogen-total. In *Methods of Soil Analysis Part 3. Chemical Methods*; Sparks, D.L., Page, A.L., Helmke, P.A., Loeppert, R.H., Eds.; SSSA and ASA: Madison, WI, USA, 1996; pp. 1085–1121.
30. Loeppert, R.; Suarez, L. Carbonate and gypsum. In *Methods of Soil Analysis. Part 3. Chemical Methods*; Sparks, D.L., Page, A.L., Helmke, P.A., Loeppert, R.H., Eds.; SSSA and ASA: Madison, WI, USA, 1996; pp. 1085–1121.

31. Castellanos-Navarrete, A.; Chocobar-Guerra, A.; Cox, R.; Fonteyne, S.; Govaerts, B.; Jespers, N.; Kienle, F.; Sayre, K.; Verhulst, N. *Infiltración: Guía útil para Comparar las Prácticas de Manejo de Cultivo*; CIMMYT: México D.F., Mexico, 2013; pp. 1–7.
32. Dick, J.; Quick, J. A modified screening test for rapid estimation of gluten strength in early-generation durum wheat breeding lines. *Cereal Chem.* **1983**, *60*, 315–318.
33. Singh, N.K.; Shepherd, K.W.; Cornish, G.B. A simplified SDS-PAGE procedure for separating LMW subunits of glutenin. *J. Cereal Sci.* **1991**, *14*, 203–208. [CrossRef]
34. Mcintosh, R.; Yamazaki, Y.; Dubcovsky, J.; Rogers, W.; Morris, C.; Appels, R.; Xia, X. Catalogue of gene symbols for wheat. *Proteins* **2013**, 83.
35. Wricke, G. Uber eine Methode zur Erfassung der okologischen Streubreite in Feldverzuchen. *Z. Pflanzenzuchtg* **1962**, *47*, 92–96.
36. Gauch, H.; Zobel, R.W. Identifying mega-environments and targeting genotypes. *Crop Sci.* **1997**, *37*, 311–326. [CrossRef]
37. Di Rienzo, J.; Casanoves, F.; Balzarini, M.; Gonzalez, L.; Tablada, M.; Robledo, C. *InfoStat*; University Argentina: Córdoba, Argentina, 2017.
38. García, A.G. *Cultivos Herbáceos Extensivos*, 6th ed.; Mundi-Prensa Libros: Madrid, Spain, 1999; pp. 26–27.
39. Lazaro, R.; Rodrigo, F.; Gutiérrez, L.; Domingo, F.; Puigdefábregas, J. Analysis of a 30-year rainfall record (1967–1997) in semi–arid SE Spain for implications on vegetation. *J. Arid Environ.* **2001**, *48*, 373–395. [CrossRef]
40. Noy-Meir, I. Desert ecosystems: Environment and producers. *Annu. Rev. Ecol. Syst.* **1973**, *4*, 25–51. [CrossRef]
41. Beck, H.E.; Zimmermann, N.E.; McVicar, T.R.; Vergopolan, N.; Berg, A.; Wood, E.F. Present and future Köppen-Geiger climate classification maps at 1-km resolution. *Sci. Data* **2018**, *5*, 180214. [CrossRef]
42. Royo, C.; Abaza, M.; Blanco, R.; del Moral, L.F.G. Triticale grain growth and morphometry as affected by drought stress, late sowing and simulated drought stress. *Funct. Plant Biol.* **2000**, *27*, 1051–1059. [CrossRef]
43. Diacono, M.; Castrignanò, A.; Troccoli, A.; De Benedetto, D.; Basso, B.; Rubino, P. Spatial and temporal variability of wheat grain yield and quality in a Mediterranean environment: A multivariate geostatistical approach. *Field Crops Res.* **2012**, *131*, 49–62. [CrossRef]
44. López-Bellido, L.; López-Bellido, R.J.; Castillo, J.E.; López-Bellido, F.J. Effects of long-term tillage, crop rotation and nitrogen fertilization on bread-making quality of hard red spring wheat. *Field Crops Res.* **2001**, *72*, 197–210. [CrossRef]
45. Sanchez-Garcia, M.; Álvaro, F.; Martín-Sánchez, J.A.; Sillero, J.C.; Escribano, J.; Royo, C. Breeding effects on the genotype× environment interaction for yield of bread wheat grown in Spain during the 20th century. *Field Crops Res.* **2012**, *126*, 79–86. [CrossRef]
46. Hoogendoorn, J.; Rickson, J.; Gale, M. Differences in leaf and stem anatomy related to plant height of tall and dwarf wheat (Triticum aestivum L.). *J. Plant Physiol.* **1990**, *136*, 72–77. [CrossRef]
47. Gadea, M. *Trigos Cultivados en Espania y Nuevas Variedades Recomendables*; Ministerio de Agricultura: Madrid, Spain, 1958.
48. Slafer, G.A.; Andrade, F.H. Changes in physiological attributes of the dry matter economy of bread wheat (*Triticum aestivum*) through genetic improvement of grain yield potential at different regions of the world. *Euphytica* **1991**, *58*, 37–49. [CrossRef]
49. Lopes, M.; Reynolds, M.; Manes, Y.; Singh, R.; Crossa, J.; Braun, H. Genetic yield gains and changes in associated traits of CIMMYT spring bread wheat in a "historic" set representing 30 years of breeding. *Crop Sci.* **2012**, *52*, 1123–1131. [CrossRef]
50. Lopes, M.S.; El-Basyoni, I.; Baenziger, P.S.; Singh, S.; Royo, C.; Ozbek, K.; Aktas, H.; Ozer, E.; Ozdemir, F.; Manickavelu, A.; et al. Exploiting genetic diversity from landraces in wheat breeding for adaptation to climate change. *J. Exp. Bot.* **2015**, *66*, 3477–3486. [CrossRef]
51. Wiegand, C.; Cuellar, J. Duration of Grain Filling and Kernel Weight of Wheat as Affected by Temparature. *Crop Sci.* **1981**, *21*, 95–101. [CrossRef]
52. Dias, A.; Lidon, F. Evaluation of grain filling rate and duration in bread and durum wheat, under heat stress after anthesis. *J. Agron. Crop Sci.* **2009**, *195*, 137–147. [CrossRef]
53. Farooq, M.; Flower, K.; Jabran, K.; Wahid, A.; Siddique, K.H. Crop yield and weed management in rainfed conservation agriculture. *Soil Tillage Res.* **2011**, *117*, 172–183. [CrossRef]

54. Iglesias, A.; Mougou, R.; Moneo, M.; Quiroga, S. Towards adaptation of agriculture to climate change in the Mediterranean. *Reg. Environ. Chang.* **2011**, *11*, 159–166. [CrossRef]
55. Rodríguez, J.; Álvaro-Fuentes, J.; Gonzalo, J.; Gil, C.; Ramos-Miras, J.; Corbí, J.G.; Boluda, R. Assessment of the soil organic carbon stock in Spain. *Geoderma* **2016**, *264*, 117–125. [CrossRef]
56. Annicchiarico, P.; Pecetti, L. Developing a tall durum wheat plant type for semi-arid, Mediterranean cereal–livestock farming systems. *Field Crops Res.* **2003**, *80*, 157–164. [CrossRef]
57. Ruiz, M.; Giraldo, P.; González, J.M. Phenotypic variation in root architecture traits and their relationship with eco-geographical and agronomic features in a core collection of tetraploid wheat landraces (*Triticum turgidum* L.). *Euphytica* **2018**, *214*, 54. [CrossRef]
58. Aguilera, E.; Lassaletta, L.; Gattinger, A.; Gimeno, B.S. Managing soil carbon for climate change mitigation and adaptation in Mediterranean cropping systems: A meta-analysis. *Agric. Ecosyst. Environ.* **2013**, *168*, 25–36. [CrossRef]
59. López-Bellido, L.; Fuentes, M.; Castillo, J.; López-Garrido, F. Effects of tillage, crop rotation and nitrogen fertilization on wheat-grain quality grown under rainfed Mediterranean conditions. *Field Crops Res.* **1998**, *57*, 265–276. [CrossRef]
60. Morris, C.F.; Paszczynska, B.; Bettge, A.D.; King, G.E. A critical examination of the sodium dodecyl sulfate (SDS) sedimentation test for wheat meals. *J. Sci. Food Agric.* **2007**, *87*, 607–615. [CrossRef]
61. Payne, P.I.; Nightingale, M.A.; Krattiger, A.F.; Holt, L.M. The relationship between HMW glutenin subunit composition and the bread-making quality of British-grown wheat varieties. *J. Sci. Food Agric.* **1987**, *40*, 51–65. [CrossRef]
62. Rogers, W.; Payne, P.; Harinder, K. The HMW glutenin subunit and gliadin compositions of German-grown wheat varieties and their relationship with bread-making quality. *Plant Breed.* **1989**, *103*, 89–100. [CrossRef]
63. Giraldo, P.; Rodriguez-Quijano, M.; Simon, C.; Vazquez, J.F.; Carrillo, J.M. Allelic variation in HMW glutenins in Spanish wheat landraces and their relationship with bread quality. *Span. J. Agric. Res.* **2010**, *8*, 1012–1023. [CrossRef]
64. CERERE Project (EU H2020). Available online: http://cerere2020.eu/wp-content/uploads/2019/01/211205-2PA-Baking-traditional-varieties-RAS-EN.pdf (accessed on 22 July 2019).
65. Ruiz, M.; Carrillo, J.M. Relationships between different prolamin proteins and some quality properties in durum wheat. *Plant Breed.* **1995**, *114*, 40–44. [CrossRef]
66. Gathala, M.K.; Ladha, J.; Saharawat, Y.S.; Kumar, V.; Kumar, V.; Sharma, P.K. Effect of tillage and crop establishment methods on physical properties of a medium-textured soil under a seven-year rice-wheat rotation. *Soil Sci. Soc. Am. J.* **2011**, *75*, 1851–1862. [CrossRef]
67. Plaza-Bonilla, D.; Álvaro-Fuentes, J.; Hansen, N.C.; Lampurlanés, J.; Cantero-Martínez, C. Winter cereal root growth and aboveground–belowground biomass ratios as affected by site and tillage system in dryland Mediterranean conditions. *Plant Soil* **2014**, *374*, 925–939. [CrossRef]
68. Chaghazardi, H.R.; Jahansouz, M.R.; Ahmadi, A.; Gorji, M. Effects of tillage management on productivity of wheat and chickpea under cold, rainfed conditions in western Iran. *Soil Tillage Res.* **2016**, *162*, 26–33. [CrossRef]
69. Gürsoy, S.; Sessiz, A.; Malhi, S. Short-term effects of tillage and residue management following cotton on grain yield and quality of wheat. *Field Crops Res.* **2010**, *119*, 260–268. [CrossRef]
70. Carr, P.M.; Horsley, R.D.; Poland, W.W. Tillage and seeding rate effects on wheat cultivars. *Crop Sci.* **2003**, *43*, 210–218. [CrossRef]
71. Honsdorf, N.; Mulvaney, M.J.; Singh, R.P.; Ammar, K.; Burgueño, J.; Govaerts, B.; Verhulst, N. Genotype by tillage interaction and performance progress for bread and durum wheat genotypes on irrigated raised beds. *Field Crops Res.* **2018**, *216*, 42–52. [CrossRef]