

GRAIN QUALITY OF TETRAPLOID WHEAT TRITICUM TIMOPHEEVII (ZHUK.) ZHUK.

Relina L.I., Boguslavskiy R.L., Vecherska L.A., Didenko S.Yu., Golik O.V., Sheliakina T.A.,
Pozdniakov V.V.

Plant Production Institute nd. a. V.Ya. Yuriev of NAAS, Ukraine

The article is devoted to the comprehensive investigation of the quality parameters of tetraploid wheat (*Triticum timopheevii*) grain. Particular attention is paid to prospects of involving *T. timopheevii* in breeding programs as a resource of valuable quality and technology properties.

Key words: *Triticum timopheevii*, grain quality, protein content, carotenoids, total antioxidant activity, zinc, iron, copper, vitreousness, grain hardness

Introduction. *Triticum timopheevii* or Timopheev's wheat is a cultivated tetraploid wheat. It is an endemic crop of the piedmonts of western Georgia [1]. The species has probably been domesticated in Georgia. The domesticated form is restricted to western Georgia. Timopheev's wheat is believed to have evolved in isolation from the more common tetraploid wheat species *T. durum* Desf., *T. turgidum* L. as also from its putative wild ancestor *T. araraticum* Jakubz.

It is suitable for sandy, loamy and clay soils and prefers moist well-drained soil. Soil pH can be acidic, neutral or alkaline. It is a light-demanding plant [2].

T. timopheevii is highly resistant to head smut [3]. It is also immune to root rots, powdery mildew, leaf, stem, yellow rusts, Septoria blotch etc. [3, 4].

There have been successful attempts to involve *T. timopheevii* in breeding since the late 1800th [4, 5, 6, 7, 8, 9]. *T. timopheevii* was crossed with common wheat. The effect of *T. timopheevii* introgression fragments on resistance to leaf and stem rusts, powdery mildew and a number of quantitative traits was evaluated in introgressive lines of common wheat [7]. The lines with an introgressive fragment of the 5G chromosome were 100% resistant to Western Siberian populations of leaf rust and stem rust that was typical for Omsk region. Lines with a fragment of the 2G chromosome were resistant to Western Siberian populations of stem rust. No negative influence of alien material from *T. timopheevii* on the yield and other quantitative traits of common wheat was observed, indicating that *T. timopheevii* can be used in breeding as donors of resistance to fungal diseases, which was further confirmed by [8, 9, 10].

Y.A. Andreev et al. [11] discovered highly homologous wamp genes in *T. timopheevii*. These genes encode hevein-like plant defense peptides have antifungal activity and are accumulated in response to phytopathogen challenge. They also participate in plant response also to abiotic stress, since high salt concentrations enhanced their expression.

Thus, *T. timopheevii* is a promising object for breeding, though little studied in terms of grain quality, and these characteristics of wheat grain are drawing increasing attention nowadays. Grain quality is determined by many parameters such as protein and starch contents and compositions, vitamin and antioxidant contents, micronutrient amounts, etc. Augmentation in grain nutrient levels (biofortification), either agronomically (fertilization) or genetically (breeding), is thought to be a promising and cost-effective approach to alleviating malnutrition and related health problems [12, 13, 14, 15, 16]. This solution, however, requires a comprehensive exploration of potential genetic resources. Therefore, our objective was to

evaluate the protein content, carotenoid level, antioxidant activity and trace mineral contents in *T. timopheevii* grain as well as performance and processing parameters of *T. timopheevii* grain.

Materials and methods. The analyses were carried out on *T. timopheevii* from a collection of the National Center for Plant Genetic Resources of Ukraine. The plants were grown on typical black soil. The cultivars used for comparisons (emmer Holikovska and durum wheat Spadshchyna) were grown in plots located in the same field with *T. timopheevii* using identical agronomic techniques. Grain harvested in 2015, 2016 and 2017 (years with various weather conditions) was used in analyses.

The protein content was determined by Kjeldahl digestion [17]. The carotenoid level was spectrophotometrically assessed in acetone extracts as described in [18, 19]. The total antioxidant activity was investigated by DPPH• assay [20]. The contents of iron, zinc and copper were determined by atomic absorption spectrometry [21]. The test weight and vitreousness were evaluated in compliance with [22]. The grain hardness was determined on a YPD-300 hardness tester (Ltpm China) (measuring force applied to crush kernels) by the method developed by A.V. Yarosh et al [23] and expressed in newtons.

Results and discussion. The protein content in *T. timopheevii* grain was within 18.2–16.5% (Table 1), depending on the year, which is rather high, as good durum wheat grain contains 15–18 % of protein (grade I grain has $\geq 14.0\%$ of protein [24]). For example, the protein content in grain of reference durum wheat cv. Spadshchyna bred at the Plant Production Institute named after V. Ya. Yuriev of NAAS ranges within 14.5–16.5%. 2017 was the most favorable year for protein accumulation. The protein content variation can be attributed to weather fluctuations during crucial periods in the plant development. The grain accumulated 18.2% of protein, when the precipitations amounts were 26 and 39 mm during the phases of green mass development and grain filling, respectively. Increase in the precipitations amount was associated with a reduction in the protein content, though the species prefers moist conditions. This can be due to insufficient drainage of soil, as the soil in the cultivation site was moderately clayey with medium drainage, and *T. timopheevii* does well on well-drained soils [2]. There was no apparent relationship between the protein content and temperatures during the crucial phases of the plant development. Despite this variation, high protein content in grain seems to be a consistently expressed trait in *T. timopheevii*, and this species belongs to high-protein wheats.

Table 1

Biochemical parameters of *Triticum timopheevii* grain, 2015–2017

Year	Protein content, %	Carotenoid content, mg/kg	TAOA, CGAE/ g of seeds	Earing date	Green mass development		Grain filling	
					Σ_p , mm	t_{av} , °C	Σ_p , mm	t_{av} , °C
2015	16.5	3.54	608.4	06.10.2015	58	16.3	102	20.3
2016	17.4	2.72	620.3	06.27.2016	123	19.6	96	23.1
2017	18.2	3.10	628.1	07.01.2017	26	19.1	39	22.6

Staples are not considered an important source of vitamins, antioxidants or minerals in the diet. However, there is an opinion [25] that because of high staple consumption, any increase in concentrations of these substances may have a significant effect on human nutrition and health. Wheat is the major staple food crop in many countries, contributing 28% of the world's edible dry matter [26].

Carotenoid content is a determinant of wheat nutritional value and affects end-product quality. Wheat grain generally contains very low carotenoid amounts and in order to enrich wheat grain with carotenoids, new high-carotenoid sources are searched for. The carotenoid content in *T. timopheevii* grain was medium: 2.72–3.54 mg/kg (Table 1). It is considered that high quality

bright-yellow pasta can be made from grain containing not less than 5.5 mg/kg of carotenoids [27]. Hence, *T. timopheevii* cannot be referred to high-carotenoid ones.

Antioxidant content is another determinant of wheat nutritional value. The total antioxidant activity in *T. timopheevii* grain amounted to 618.2 chlorogenic acid equivalents (CGAE) /g of seeds in 2017, reducing in the other study years (see Table 1). The peak content of antioxidants in the years with the minimal precipitation during the wheat development may be accounted for by enhanced non-specific protection against stress. A positive correlation was observed between seed antioxidants and drought tolerance in other plant species [28]. The average antioxidant activity in *T. timopheevii* grain remains higher than that in reference durum wheat grain, cv. Spadshchyna (525.4±38.9 CGAE /g of seeds). Thus, *T. timopheevii* can be tested for using in wheat breeding for high antioxidant content.

Some minerals are essential in metabolism or for the synthesis of essential compounds. Bread and breakfast cereals are sometimes specifically fortified with iron [29], therefore, there is a chance to breed high-iron wheat cultivars. The iron content in commercial durum wheat varies within 25.7–40.5 mg/kg [30]. *T. timopheevii* grain contains 39.27–55.90 mg/kg of iron (see Table 2), which is considerably higher than the iron levels in commercial durum wheat cultivars and comparable to the iron content in Polish emmer grain (49 mg/kg, though such comparisons should be drawn with reservations, because growing conditions may vary a lot) [31] and in cv. Holikovska grain (around 40 mg/kg) bred at the Plant Production Institute named after V.Ya. Yuriev of NAAS). This variation can be attributed to weather fluctuations during crucial periods in the plant development: the grain accumulated 55.90 mg/kg of iron, when the precipitations amounts were 26 and 39 mm during the phases of green mass development and grain filling, respectively. Increase in the precipitations amount was associated with a reduction in the iron content. Thus, in general, the iron content changed in parallel with the protein content. This was expected, since the high grain protein content gene (*GPC-B1*) was also shown to confer higher concentrations of both Fe and Zn in grain [32, 33]. Despite this variation, high iron content in grain appears to be genetically intrinsic to *T. timopheevii*.

Table 2

Mineral contents in *Triticum timopheevii* grain in different years

Year	Minerals			Earing date	Green mass development		Grain filling	
					Σ_p , mm	t_{av} , °C	Σ_p , mm	t_{av} , °C
	Zn	Fe	Cu					
2015	36.334	40.040	4.455	06.10.2015	58	16.3	102	20.3
2016	36.524	39.270	2.790	06.27.2016	123	19.6	96	23.1
2017	41.041	55.900	1.860	07.01.2017	26	19.1	39	22.6

Note: Σ_p – precipitation amount, t_{av} – average temperature.

Zinc is also an essential trace element for humans. Wheat (especially germ and bran) is among the food plants that contain the most zinc [34]. For fortification, 2003 review recommended cereals as a cheap, stable source that is as easily absorbed [35]. The zinc content in commercial durum wheat varies within 24.8–48.8 mg/kg [30]. ContiME et al. [36] reported that Italian durum wheat contained 24 mg/kg of zinc. The maximum allowable concentration of zinc in grain is 50.0 mg/kg [37]. *T. timopheevii* grain contains 36.33–41.04 mg/kg of zinc (see Table 2), which is comparable to commercial durum wheat and our emmer, cv. Holikovska (around 31.0 mg/kg), and somewhat less than in Polish emmer grain (54 mg/kg, as Suchowilska et al reported [31]). The zinc content-weather conditions relationship was similar to the protein/iron content-weather conditions relationship (see the discussion above) Correlations between Zn and Fe contents were positive for wild emmer [32, 38, 39], and domesticated emmer [40].

Copper is another essential trace element. Italian durum wheat, for example, contains 3.5 mg/kg of copper [36]. The variations in this parameter can be wide: 1.8–39.7 mg/kg in durum

wheatmilling products [41]. In Russian wheat grain the copper content ranged within 2.0–12.8 mg/kg, depending on the cultivation site [42]. Other Russian researchers report that the copper level in spring wheat grain averaged 5.15 ± 0.40 mg/kg (throughout 10 years), with the maximum allowable concentration of 10 mg/kg [37]. Suchowilska et al [31] reported that grain of a related species, *Triticum dicoccum*, contained 4.4 mg/kg of copper. *T. timopheevii* grain contained of 1.86–4.46 mg/kg of copper in different years (see Table 2). Thus, such levels can satisfy the need of human body for copper, on the one hand, and are far below the maximum allowable concentration, on the other hand. The copper content was maximal in the years, when the average air temperature during the phases of green mass development and grain filling was relatively low: 16.3 and 20.3°C, respectively. Rise in temperature to 19.1–19.6°C and to 22.6–23.1°C, respectively, was associated with lower copper content. Unlike the iron and zinc contents, we observed no relationship between the copper content and the precipitation amount.

Concurrently with biochemical characterization, we measured performance and processing parameters of *T. timopheevii*. The 1000-seed weight was 34.29 g (see Table 3), meaning that *T. timopheevii* has medium-sized grain. The test weight and vitreousness are criteria for determining grain grade. The grain unit was around 846 g/L, which is sufficiently high, as the minimal grain unit for durum wheat is set on 700 g/L, and grade I grain has ≥ 750 g/L [24]. The vitreousness was markedly high – 100%, which is valuable for easy milling (grade I grain has $\geq 70\%$ vitreousness [24]). The grain hardness is one of the key determinants of milling behavior and has a great influence on flour and dough quality [43, 44, 45]. For example, the grain hardness was shown to correlate with bread-making quality [46, 47]. The *T. timopheevii* grain hardness was 286N. It is difficult to compare different researchers' data, as they use different techniques and devices to measure the grain hardness. However, Veha et al. [48] cross-checked the Hardness Index (HI) produced Perten SKCS 4100 equipment against maximum breaking force in Newtons produced by Lloyd 1000R Testing Machines. Using their data, we can assume that 286 N measured on a YPD-300 hardness tester corresponds approximately HI 68. Using Szabó et al's data [49], we obtain a similar result. This means that *T. timopheevii* is likely to belong to hard wheats according to Haraszi et al's classification [50, 51].

Table 3

Technological parameters of *Triticum timopheevii* grain, 2015–2017

Year	Grain hardness, N	Test weight, g/L	Vitreousness, %	1000-grain weight, g	Earling date	Green mass development		Grain filling	
						Σ_p , mm	t_{av} , °C	Σ_p , mm	t_{av} , °C
2015	283	842	99	34.1	06.10.2015	58	16.3	102	20.3
2016	279	850	100	34.6	06.27.2016	123	19.6	96	23.1
2017	296	846	100	34.3	07.01.2017	26	19.1	39	22.6

Conclusions. Thus, our results have demonstrated that

- 1) *T. timopheevii* has medium-sized grain;
- 2) *T. timopheevii* is noticeable for a high antioxidant activity, sufficient iron and zinc contents, balanced copper content, exclusively high vitreousness and high grain harness;
- 3) *T. timopheevii* cannot be referred to high-carotenoid species.

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ЯКІСТЬ ЗЕРНА ТЕТРАПЛОЇДНОЇ ПШЕНИЦІ *TRITICUM TIMOPHEEVII* (ZHUK.) ZHUK

Реліна Л.І., Богуславський Р.Л., Вечерська Л.А., Діденко С.Ю., Голік О.В., Шелякіна Т.А., Поздняков В.В.

Інститут рослинництва ім. В.Я. Юр'єва НААН, Україна

Мета досліджень. Визначення вмісту білка та каротиноїдних пігментів, загальної антиоксидантної активності, рівня мікроелементів в зерні *T. timopheevii* та продуктивності і технологічних показників зерна *T. timopheevii*.

Матеріали та методи. Зразки *T. timopheevii* для досліджень було отримано з колекції Національного центру генетичних ресурсів рослин України. Грунт – типовий чорнозем. Сорти, які було використано для порівняння, вирощувались на одному полі з *T. timopheevii* із застосуванням однакових агротехнологій. Для вивчення було використано зерно, зібране в 2015, 2016 та 2017 (роки з різними погодними умовами). Вміст білка визначали за методом Кьельдаля. Рівень каротиноїдних пігментів оцінювали в екстрагованих ацетоном фракціях методом спектрофотометрії. Загальну антиоксидантну активність досліджували за допомогою аналізу з використанням стабільного вільного радикалу DPPH. Вміст заліза, цинку та міді визначали методом атомно-абсорбційної спектрометрії. Натура та склоподібність оцінювалися відповідно до затверджених методик. Твердість зерна визначалась на твердомері YPD-300 (який вимірює силу, що необхідно докласти для руйнування зернівки, в ньютонках) методом, розробленим А.В. Ярошем та ін.

Результати і обговорення. Вміст білка в зерні *T. timopheevii* склав 18,2–16,5 %, в залежності від року, що є досить високим, оскільки якісне зерно твердої пшениці містить 15–18 % білка. Зерно *T. timopheevii* накопичувало 18,2 % білка, коли сума опадів була 26 і 39 мм під час фаз розвитку зеленої маси та наливу зерна відповідно. Підвищення суми опадів було пов'язано із зниженням вмісту білка, хоча цей вид надає перевагу вологим умовам. Це можна пояснити недостатнім дренажуванням ґрунту, оскільки ґрунт в місці вирощування помірно глинистий з середнім дренажуванням, а *T. timopheevii* добре почувається на добре дренажованих ґрунтах. Загальна антиоксидантна активність в зерні *T. timopheevii* складала 618,2 екв. хлорогенової кислоти в 2017 р., знижуючись в інші роки дослідження, що вище, ніж в зерні сорту твердої пшениці Спадщина, створеному в Інституті рослинництва ім. В.Я. Юр'єва НААН (525,4±38,9 екв. хлорогенової кислоти/г насіння). Максимальний вміст каротиноїдів в роки з мінімальною сумою опадів під час розвитку пшениці може бути обумовлено посиленням неспецифічного захисту від стресу. Вміст каротиноїдних пігментів в зерні *T. timopheevii* був середнім: 2,72–3,54 мг/кг. Оскільки вважається, що високоякісні макарони яскраво-жовтого кольору можна виготовляти з зерна, що містить не менше 5,5 мг/кг каротиноїдів, цей вид не можна вважати висококаротиноїдним. Зерно досліджуваних зразків *T. timopheevii* містить 39,27–55,90 мг/кг заліза, що значно перевищує рівень заліза в комерційних сортах твердої пшениці та порівнянне з вмістом заліза в зерні польської полби (49 мг/кг) та близько в зерні сорту Голіковська, створеному в Інституті рослинництва ім. В.Я. Юр'єва НААН (40 мг/кг). В цілому вміст заліза змінюється паралельно з вмістом білка, що було очікувано, оскільки дані літератури свідчать про те, що ген *grainproteincontent* (*GPC-B1*) також контролює накопичення Fe та Zn в зерні. Зерно *T. timopheevii* містить 36,33–41,04 мг/кг цинку, що можна порівняти з комерційною твердою пшеницею і нашим сортом полби Голіковська (близько 31,0 мг/кг) і є дещо нижчим, ніж у зерні полби в інших роботах. Варіації в рівнях білка, заліза і цинку можуть бути обумовлені змінами в погодних умовах під час ключових періодів розвитку рослин. Зв'язок вмісту цинку з погодними умовами був подібним до ситуації з вмістом білка і заліза та погодними умовами. Зерно *T. timopheevii* містить 1,86–4,46 мг/кг міді в різні роки. Такий рівень, з одного боку, може

задовольнити потребу організму людини, а, з іншого боку, є значно нижчим від гранично допустимої концентрації. Вміст міді був максимальним у роки, коли середня температура повітря на етапах розвитку зеленої маси та наливу зерна була відносно низькою: 16,3 та 20,3 °С відповідно. Підвищення температури до 19,1–19,6 °С та до 22,6–23,1 °С, відповідно, було пов'язано з меншим вмістом міді. На відміну від вмісту заліза та цинку, ми не спостерігали взаємозв'язку між вмістом міді та кількістю опадів.

Ми також вивчали елементи продуктивності та технологічні параметри *T. timopheevii*. Маса 1000 зерен склала 34,29 г, що означає, що *T. timopheevii* має зерно середнього розміру. Натура становила 846 г/л, що є досить високим показником, оскільки зерно I класу має натуру ≥ 750 г/л. Склоподібність була високою – 100 %, що є цінною ознакою для більш якісного помелу зерна. Твердість зерна *T. timopheevii* становила 286 N. Ми можемо вважати, що 286 N, визначена на твердомері YPD-300, відповідає приблизно НІ 68. Це означає, що *T. timopheevii*, ймовірно, належить до твердих пшениць відповідно до класифікації Haraszi та ін.

Висновки. Наші результати продемонстрували, що 1) *T. timopheevii* має зерно середнього розміру; 2) *T. timopheevii* характеризується високою антиоксидантною активністю, достатнім вмістом заліза та цинку, збалансованим вмістом міді, а також виключно високою склоподібністю та високою твердістю зерна; 3) *T. timopheevii* не можна віднести до високо каротиноїдних видів.

Ключові слова: *Triticum timopheevii*, якість зерна, вміст білка, каротиноїдні пігменти, загальна антиоксидантна активність, цинк, залізо, мідь, склоподібність, твердість зерна

КАЧЕСТВО ЗЕРНА ТЕТРАПЛОИДНОЙ ПШЕНИЦЫ TRITICUM ТИМОФЕЕВИИ (ZHUK.) ZHUK.

Релина Л. И., Богуславский Р. Л., Вечерская Л. А., Диденко С. Ю., Голик О. В., Шелякина Г. А., Поздняков В. В.
Институт растениеводства им. В. Я. Юрьева НААН, Украина

Цель исследований. Определение содержания белка и каротиноидных пигментов, общей антиоксидантной активности, уровня микроэлементов в зерне *T. timopheevii* и производительности и технологических показателей зерна *T. timopheevii*.

Материалы и методы. Образцы *T. timopheevii* для исследований были получены из коллекции Национального центра генетических ресурсов растений Украины. Почва - типичный чернозем. Сорты, которые были использованы для сравнения, выращивались на одном поле с *T. timopheevii* с применением одинаковых агротехнологий. Для изучения было использовано зерно, собранное в 2015, 2016 и 2017 (годы с различными погодными условиями). Содержание белка определяли по методу Кьельдаля. Уровень каротиноидных пигментов оценивали в экстрагированных ацетоном фракциях методом спектрофотометрии. Общую антиоксидантную активность исследовали с помощью анализа с использованием стабильного свободного радикала DPPH. Содержание железа, цинка и меди определяли методом атомно-абсорбционной спектрометрии. Натура и стекловидность оценивались в соответствии с утвержденными методиками. Твердость зерна определялась на твердомере YPD-300 (измеряет силу, которую необходимо приложить для разрушения зерновки, в Ньютонах) методом, разработанным А.В. Ярошем и др.

Результаты и обсуждение. Содержание белка в зерне *T. timopheevii* составил 18,2–16,5 %, в зависимости от года, что является достаточно высоким, поскольку качественное зерно твердой пшеницы содержит 15–18 % белка. Зерно *T. timopheevii* накапливало 18,2 % белка, когда сумма осадков была 26 и 39 мм в период развития зеленой массы и налива зерна соответственно. Повышение суммы осадков было связано со снижением содержания белка, хотя этот вид предпочитает влажные условия. Это можно

объяснить недостаточным дренированием почвы, поскольку почва в месте выращивания умеренно глинистая со средним дренированием, а *T. timopheevii* хорошо чувствует себя на хорошо дренированных почвах. Общая антиоксидантная активность в зерне *T. timopheevii* составляла 618,2 экв. хлорогеновой кислоты в 2017 г., снижаясь в другие годы исследования, что выше, чем в зерне сорта пшеницы твердой Спадщина, созданном в Институте растениеводства им. В.Я. Юрьева НААН (525,4±38,9 экв. хлорогеновой кислоты / г семян). Максимальное содержание каротиноидов в годы с минимальной суммой осадков во время развития пшеницы может быть обусловлено усилением неспецифической защиты от стресса. Содержание каротиноидных пигментов в зерне *T. timopheevii* был средним: 2,72–3,54 мг/кг. Поскольку считается, что высококачественные макароны ярко-желтого цвета можно изготавливать из зерна, содержащего не менее 5,5 мг/кг каротиноидов, этот вид нельзя считать высококаротиноидным. Зерно исследуемых образцов *T. timopheevii* содержит 39,27–55,90 мг/кг железа, что значительно превышает уровень железа в коммерческих сортах твердой пшеницы и сравнимо с содержанием железа в зерне польской полбы (49 мг/кг) и примерно в зерне сорта Голиковська, созданном в Институте растениеводства им. В.Я. Юрьева НААН (40 мг/кг). В целом содержание железа меняется параллельно с содержанием белка, что было ожидаемо, поскольку данные литературы свидетельствуют о том, что ген *grainproteincontent* (GPC-B1) также контролирует накопление Fe и Zn в зерне. Зерно *T. timopheevii* содержит 36,33–41,04 мг / кг цинка, что можно сравнить с коммерческой твердой пшеницей и нашим сортом полбы Голиковська (около 31,0 мг/кг) и несколько ниже, чем в зерне полбы в других работах. Вариации в уровнях белка, железа и цинка могут быть обусловлены изменениями в погодных условиях во время ключевых периодов развития растений. Связь содержания цинка с погодными условиями была подобной ситуации с содержанием белка и железа и погодными условиями. Зерно *T. timopheevii* содержит 1,86–4,46 мг / кг меди в разные годы. Такой уровень, с одной стороны, может удовлетворить потребность организма человека, а с другой стороны, значительно ниже предельно допустимой концентрации. Содержание меди было максимальным в годы, когда средняя температура воздуха на этапах развития зеленой массы и налива зерна была относительно низкой: 16,3 и 20,3 С соответственно. Повышение температуры до 19,1–19,6 С и к 22,6–923,1 С соответственно, было связано с меньшим содержанием меди. В отличие от содержания железа и цинка, мы не наблюдали взаимосвязи между содержанием меди и количеством осадков.

Мы также изучали элементы производительности и технологические параметры *T. timopheevii*. Масса 1000 зерен составила 34,29 г, что означает, что *T. timopheevii* имеет зерно среднего размера. Натура составляла 846 г/л, что является достаточно высоким показателем, поскольку зерно I класса имеет натуру ≥ 750 г/л. Стекловидность была высокой – 100 %, что является ценным признаком для более качественного помола зерна. Твердость зерна *T. timopheevii* составляла 286 N. Мы можем считать, что 286 N, определенная на твердомере YPD-300, соответствует примерно HI 68. Это означает, что *T. timopheevii*, вероятно, относится к твердым пшеницам в соответствии с классификацией Naraszi и др.

Выводы. Наши результаты показали, что 1) *T. timopheevii* имеет зерно среднего размера; 2) *T. timopheevii* характеризуется высокой антиоксидантной активностью, достаточным содержанием железа и цинка, сбалансированным содержанием меди, а также исключительно высокой стекловидностью и высокой твердостью зерна; 3) *T. timopheevii* нельзя отнести к высококаротиноидным видам.

Ключевые слова: *Triticum timopheevii*, качество зерна, содержание белка, каротиноидные пигменты, общая антиоксидантная активность, цинк, железо, медь, стекловидность, твердость зерна

GRAIN QUALITY OF TETRAPLOID WHEAT TRITICUM TIMOPHEEVII (ZHUK.) ZHUK.

Relina L.I., Boguslavskiy R.L., Vecherska L.A., Didenko S.Yu., Golik O.V., Sheliakina T.A.,
Pozdniakov V.V.
Plant Production Institute nd. a. V.Ya. Yuriev of NAAS, Ukraine

Purpose and objectives. To evaluate the protein content, carotenoid level, antioxidant activity and trace mineral contents in *T. timopheevii* grain and to measure performance and processing parameters of *T. timopheevii* grain.

Materials and methods. The analyses were carried out on *T. timopheevii* from a collection of the National Center for Plant Genetic Resources of Ukraine. Plants were grown on typical black soil. The cultivars used for comparisons (emmer Holikovska and durum wheat Spadshchyna) were grown in plots located in the same field with *T. timopheevii* using identical agronomic techniques. Grain harvested in 2015, 2016 and 2017 (years with various weather conditions) was used in analyses. The protein content was determined by Kjeldahl digestion. The carotenoid level was spectrophotometrically assessed in acetone extracts. The total antioxidant activity was investigated by DPPH assay. The contents of iron, zinc and copper were determined by atomic absorption spectrometry. The grain unit and vitreousness were evaluated in compliance with conventional techniques. The grain hardness was determined on a YPD-300 hardness tester (Ltpm China) (measuring force applied to crush kernels) by the method developed by AV Yarosh et al. expressed in newtons.

Results and discussion. The protein content in *T. timopheevii* grain was within 18.2–16.5%, depending on the year, which is rather high as good durum wheat grain contains 15–18 % of protein. The grain of *T. timopheevii* accumulated 18.2% of protein, when the precipitations amounts were 26 and 39 mm during the phases of green mass development and grain filling, respectively. Increase in the precipitations amount was associated with a reduction in the protein content, though the species prefers moist conditions. This can be due to insufficient drainage of soil, as the soil in the cultivation site was moderately clayey with medium drainage, and *T. timopheevii* does well on well-drained soils. The total antioxidant activity in *T. timopheevii* grain amounted to 618.2 chlorogenic acid equivalents (CGAE) /g of seeds in 2017, reducing in the other study years, which is higher than in durum wheat grain, cv. Spadshchyna, bred at the Plant Production Institute named after VYa Yuriev of NAAS (525.4±38.9 CGAE /g of seeds). The peak content of antioxidants in the years with the minimal precipitation during the wheat development may be accounted for by enhanced non-specific protection against stress. The carotenoid content in *T. timopheevii* grain was medium: 2.72–3.54 mg/kg. Since high-quality bright-yellow pasta is considered to be made from grain containing not less than 5.5 mg/kg of carotenoids, this species cannot be referred to high-carotenoid ones. *T. timopheevii* grain contains 39.27–55.90 mg/kg of iron, which is considerably higher than the iron levels in commercial durum wheat cultivars and comparable to the iron content in Polish emmer grain (49 mg/kg) and in cv. Holikovska grain (around 40 mg/kg) bred at the Plant Production Institute named after V.Ya. Yuriev of NAAS). In general, the iron content changed in parallel with the protein content, which was expected, since literature data indicate that the high grain protein content gene (*GPC-B1*) confers higher concentrations of both Fe and Zn in grain. *T. timopheevii* grain contains 36.33–41.04 mg/kg of zinc, which is comparable to commercial durum wheat and our emmer, cv. Holikovska (around 31.0 mg/kg), and somewhat less than in emmer grain in other investigations. The variations in the protein, iron and zinc contents can be attributed to weather fluctuations during crucial periods in the plant development. The zinc content-weather conditions relationship was similar to the protein/iron content-weather conditions relationship. *T. timopheevii* grain contained 1.86–4.46 mg/kg of copper in different years. Such levels can satisfy the need of human body for copper, on the one hand, and are far below the maximum allowable concentration, on the other hand. The copper content was maximal in the years, when the average air temperature during the phases of green mass development and grain filling was

relatively low: 16.3 and 20.3 °C, respectively. Rise in temperature to 19.1–19.6 °C and to 22.6–23.1 °C, respectively, was associated with lower copper content. Unlike the iron and zinc contents, we observed no relationship between the copper content and the precipitation amount.

We also measured performance and processing parameters of *T. timopheevii*. The 1000-seed weight was 34.29 g, meaning that *T. timopheevii* has medium-sized grain. The test weight was around 846 g/L, which is sufficiently high, as grade I grain has ≥ 750 g/L. The vitreousness was markedly high 100%, which is valuable for easy milling. The *T. timopheevii* grain hardness was 286 N. We can assume that 286 N measured on a YPD-300 hardness tester corresponds approximately HI 68. This means that *T. timopheevii* is likely to belong to hard wheats according to Haraszi et al.'s classification.

Conclusions. Our results have demonstrated that 1) *T. timopheevii* has medium-sized grain; 2) *T. timopheevii* is noticeable for a high antioxidant activity, sufficient iron and zinc contents, balanced copper content, exclusively high vitreousness and high grain hardness; 3) *T. timopheevii* cannot be referred to high-carotenoid species.

Key words: *Triticum timopheevii*, grain quality, protein content, carotenoids, total antioxidant activity, zinc, iron, copper, vitreousness, grain hardness