

Winter rye as a source of raw material for production of bioethanol

Yehorov D., Zmiyevska O.

V. Yuryev Institute of plant industry of NAAS, Moskovskiyi avenue, 142, Kharkiv, 61060, Ukraine; e-mail: yuriev1908rye@gmail.com

The purpose. To calculate theoretical alcohol yield from grain of varieties and hybrids of winter rye depending on genotype. **Methods.** They studied 29 samples of winter rye in different weather conditions of years of growing. Backfilling of experiment was spent according to B.A. Dos-pehov procedure. Theoretical alcohol yield was determined by calculation method. **Results.** Average productivity of grain was 5,02 t/hectare in rainless weather environment. That exceeded average productivity of crop in Kharkiv region and Ukraine on 2,5 t/hectare. Samples of winter rye formed the heightened level of starch in grain — 61,86% in comparison to average for crop — 55%. Thus varieties generated more starch (62,41%), than hybrids (61,13%) (NSR=0,54%). Theoretical alcohol yield at samples averaged 220,48 dal/hectare. Strong correlation between theoretical alcohol yield and exit of starch from a unit of area ($r=1$), productivity of grain and exit of starch from unit of area ($r=0,99$), productivity of grain and theoretical alcohol yield ($r=0,99$) and absence of correlation between exit of starch from a unit of area and its content in grain is established. Opportunity of deriving of hybrids with high productivity of grain 1000,5 – 1309,8 g/m² and the heightened starch content 62,6 – 63,8% in grain in good weather environment is shown. Theoretical alcohol yield in such conditions made 315,3 – 585,2 dal/hectare. **Conclusions.** It is proved that created in the Institute of plant industry varieties and hybrids of winter rye have high stable productivity of grain in combination to tall exit of starch and tall theoretical alcohol yield. It ensures to it competitive strength among other alternative crops for production of bioethanol.

Key words: winter rye, hybrid, variety, bioethanol, theoretical alcohol yield.

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People's active use of Earth natural resources has a great effect on the environment of the planet, and become stronger every year. Ecological problems and rapid reduction of natural resources force the international society to care for decreasing of human's influence on the environment. One of the ways to solve this problem is a usage of alternative fuels, such as biogas, biodiesel and bioethanol. Many states of the world enhance the development of "green" power. Last years the interest in sources of renewable energy significantly increased in Ukraine too.

There is a huge number of renewable energy sources, among which is occupied a big place by sacchariferous and starch-containing crops, such as wheat, sugar beet, corn, sugar cane, girasol [1]. Corn is the best grain crop among the other crops for ethanol production because of high grain yield and starch content [2]. But as corn demands a big area and rather expensive technology for cultivation, today search of alternative crops for bioethanol production is relevant. Results of the world and domestic investigations show an application possibility of sorghum sugar [3] because of high sugar content and an opportunity to use its stalks for bioethanol. The usage of potato and banana raw materials for ethanol is a low-profitable in comparison with grain. From one ton of potatoes it is possible to get 80–100 l of 100% ethyl alcohol, whereas from one ton of grain (a rye, wheat, rice, corn) it is possible to get about 270 - 450 l [5]. Winter rye is considered as a raw materials' source for alternative fuel production, because of its high adaptability to adverse cultivation conditions and low requirements to the soil fertility, at the same time the problem of rye grain processing for high content of α -glucans and pentozans is specified [6]. Different rye grain adaptation technologies for processing to alcohol are developed for the solving of this perspective

[7-11]. As far as winter rye grows in all climatic zones of Ukraine, with technologies of grain processing to alcohol it can be valuable as an alternative crop for alternative fuel producers. Therefore our investigations are directed to definition of usage possibility of winter rye varieties and hybrids, selected at Plant Production Institute nd. by V. Ya. Yuryev NAAS, for bioethanol production.

Purpose. The purpose of investigation was the calculation of the theoretical ethanol yield from grain of winter rye varieties and hybrids depending on a genotype.

Materials and methods. Researches were conducted in 2013-2017 at the field of Plant Production Institute nd. by V. Ya. Yuryev NAAS. Weather conditions in years of research were changeable, that allowed comprehensive estimation of winter rye varieties and hybrids potential on grain yield. Conditions of winter rye vegetative period in 2013 were characterized by sufficient warm and moisture security (the sum of temperatures – 2891,8 C, the sum of rainfall – 185,9 mm, HTC (hydrothermal coefficient) – 0,6). In 2014 rainfall dropped out 3,3 times more, than in previous year, at smaller amount of heat (the sum of temperatures – 2407,4 C, the sum of rainfall – 511,2 mm, HTC – 2,1).

Features of the vegetative period in 2015-2016 were a very droughty period of autumn vegetation (September-October of the HTC – 0,2) and sufficient moisture supply during overwintering and spring and summer plant development (April-June HTC – 2,8). The vegetative period in 2016-2017 was characterized by cold spring vegetation period (average daily temperature in April did not exceed 10 C, rainfall existence was as snow with frosts in separate days about -5 C) and the droughty period in a swelling stage (HTC – 0,5), and these had an adverse effect on rye plant development.

Winter rye varieties and hybrids for food purpose, selected in Plant Production Institute nd. by V. Ya. Yuryev NAAN, were a material for researches. Samples included four varieties Pamyat Khudoyerka, Khamarka, Dikhar, Stoir and three hybrids Yupiter F₁, Saturn F₁, Slobozhanets F₁, entered in the List of plants suitable for distribution in Ukraine, and 22 experimental hybrids. The standard was the variety Pamyat Khudoyerka. Winter rye was sowed with seeding rate 4 million viable grains per hectare on plots of 10 m², in four time frequency [12]. The theoretical ethanol yield was found by a calculation method, taking into account features of starch content in samples` grain. The starch content in grain was determined by Evers`s method [13]. Statistical data processing was carried out with the aid of Microsoft Excel 2010 and Statistica 10 programs.

Results. The theoretical ethanol yield from winter rye grain is a complex sign which includes the grain yield, the starch content in grain and the starch yield per area unit. Therefore in table 1 are provided not only data of the main studied sign and of its components too.

Table 1. – The theoretical ethanol yield per area unit of winter rye varieties and hybrids, 2016-2018.

Exemplar	Grain yield, τ/ha	Starch content, %	Starch yield, τ/ha	Theoretical ethanol yield, dal/ha
Yupiter F ₁	5,30	61,51	3,26	231,38
Saturn F ₁	5,90	60,74	3,59	254,32
Slobozhanets F ₁	3,97 ¹⁾	61,15	2,43	172,17
Pamyat Khudoyerka (станд.)	4,85	62,68	3,04	215,48
Khamarka	5,48	62,47	3,42	242,46
Stoir	4,83	61,80	2,99	212,19
Dikhar	4,84	62,70	3,04	215,37
Average on hybrids	5,06	61,13	3,09	219,29
Average on varieties	5,00	62,41	3,12	221,38

Average in the trail	5,02	61,86	3,11	220,48
Average on the crop	2,50 ²⁾	55,00	1,37	97,50
LSD _{0,5}	0,81	-	0,87	61,77

¹⁾ - authentically at the level 5%

²⁾ – Average yield in Ukraine

The samples' grain yield of winter rye from 3,97 t/hectare up to 5,90 t/ha was established. The yield of the majority studied samples was in limits of standard variety yield, only the hybrid Saturn (5,90 t/he) authentically exceeded the standard Pamyat Khudoyerka. The average yield of winter rye varieties and hybrids was 5,02 t/he, that in droughty conditions of 2016-2017 was rather high, therefore according to the state statistics the average grain yield of winter rye in Kharkiv region and across Ukraine did not exceed 2,5 t/ha. It proved in turn high drought resistance of these samples.

Samples were also characterized by increased starch in grain along with high grain yield. Winter rye formed about 55% of starch on average, whereas the studied samples created 61,86% of starch on average in trail, though insignificant fluctuation of starch content from 60,74% to 62,7% depending on a genotype was noted. Having analyzed data on starch content in grain at varieties and hybrids separately, it was noted, that varieties created more starch 62,41% on average, than hybrids 61,13% LSD=0,54). Therefore, theoretically it was possible to get more starch per area unit 3,12 t/ha from varieties, than from hybrids 3,09 t/ha, and ethanol 221,38 dal/ha and 219,29 dal/ha respectively, though distinctions on the starch content, the ethanol yield and the grain yield (5,06 t/ha and 5,00 t/ha respectively) differed not considerably, that could be explained by existence of connection between the theoretical ethanol yield and its components.

It was established strong direct correlation between the theoretical ethanol yield and the starch yield per area unit ($r = 1$), the grain yield and the starch yield per area unit ($r = 0,99$), the grain yield and the theoretical ethanol yield ($r = 0,99$). Weak inverse correlation between the grain yield and the starch content ($r = -0,11$) was revealed. Connection between the theoretical ethanol yield and the starch content and between the starch yield per area unit and the starch content was not revealed. Therefore at obvious difference on starch content in grain of varieties and hybrids, the starch yield and the theoretical ethanol yield per area unit practically did not differ.

So far as weather conditions in 2016-2017 were not favorable for growth and development of winter rye plants, for comparison we gave the results of research on the theoretical ethanol yield and its components at hybrid combinations of winter rye, which are grown up in favorable weather conditions in 2013-2014.

Table 2 – The theoretical ethanol yield per area unit of winter rye experimental hybrids , 2013-2014.

Hybrid combinations	— — — —	o o c	> — — —	c — c o
I. 90691 A / I. 041736 R	874,5	62,1	5,4	386,0
I. 90691 A / I. 90689 R	1208,8	62,6	7,6	537,2
I. 90691 A / I. 932073 R	860,5	63,4	5,5	387,3
I. 90691 A / I. 011284 R	979,8	62,5	6,1	434,7
I. 90691 A / I. 063491 R	830,8	62,7	5,2	370,3
I. 90691 A / I. 933464 R	884,4	63,4	5,6	398,1
I. 90691 A / I. 931149 R	965,9	62,7	6,1	430,3
I. 90691 A / I. 052604 R	866,4	63,3	5,5	389,7
I. 90691 A / I. 022219 R	858,8	64,0	5,5	390,5
I. 90691 A / Stoir	760,0	62,8	4,8	339,2
I. 90691 A / Pamyat Khudoyerka	1018,2	62,7	6,4	453,5

I. 011201 A / I. 041736 R	1309,8	62,6	8,2	582,5
I. 011201 A / I. 90689 R	935,1	62,4	5,8	414,7
I. 011201 A / I. 932073 R	918,2	62,8	5,8	409,6
I. 011201 A / I. 011284 R	1062,9	62,4	6,6	471,1
I. 011201 A / I. 063491 R	952,4	62,9	6,0	425,4
I. 011201 A / I. 933464 R	1000,5	63,8	6,4	453,7
I. 011201 A / I. 931149 R	988,8	63,0	6,2	442,7
I. 011201 A / I. 052604 R	704,6	63,0	4,4	315,3
I. 011201 A / I. 022219 R	796,4	63,1	5,0	357,2
I. 011201 A / Stoir	789,2	63,0	5,0	353,4
I. 011201 A / Pamyat Khudoyerka	1060,8	62,6	6,6	471,6
Pamyat Khudoyerka (stand.)	670,0	61,9	4,1	290,8
Average on hybrids	937,6	62,9	5,9	376,7

Data from table 2 showed, that in favorable years hybrid combinations provided grain yield from 704,6 to 1309,8 g/m². Hybrids` potential on grain yield was rather high in comparison with the yield of standard 670,0 g/m². At the same time experimental hybrids combined a high grain yield and an increased starch content in grain in their genotype. For example hybrid combinations I. 90691 A/I. 90689 R, I. 90691 A / Pamyat Khudoyerka, I. 011201 A/I. 041736 R, I. 011201 A/I. 011284 R, I. 011201 A/I. 933464 R, I. 011201 A / Pamyat Khudoyerka created high level of yield and increased starch content 1208,8 g/m² and 62,6%, 1018,2 g/m² and 62,7%, 1309,8 g/m² and 62,6%, 1062,9 g/m² and 62,4%, 1000,5 g/m² and 63,8%, 1060,8 g/m² and 62,6% respectively.

Experimental hybrids showed high starch yield, and respectively ethanol yield per area unit. In comparison with the standard (4,1 t/ha) hybrids gave starch for 7,6-50,0% more. An ethanol yield at hybrid combinations made 315,3-582,5 dal/ha, that considerably exceeded an ethanol yield of standard 290,8 dal/ha.

In comparison with the most widespread bioenergetic crop corn, the majority of studied winter rye hybrid combinations conceded to corn hybrids on starch yield, therefore corn is more fruitful on grain and has bigger starch content. So, according to the competitive grade testing of corn hybrids at corn breeding laboratory of Plant Production Institute nd. by V. Ya. Yuryev NAAS yield of hybrids in 2013-2014 has been 7-8 t/ha, and the starch content has varied from 72,0 to 76,5%. Therefore, it is theoretically possible to get about 6 t/ha of starch from corn grain. Data of tables 2 demonstrate, that 45% of winter rye hybrids do not concede to corn on starch yield, and some of them even exceed it besides of high yield. For example, winter rye hybrid combination I. 011201 A/I. 041736 R has made starch yield 8,2 t/hectare. In addition raw materials from rye are cheaper, than from corn, for less expensive cultivation technology usage and a lack of postharvest grain completion.

Conclusions

The analysis of researches` results demonstrates, winter rye varieties and hybrids, created in Plant Production Institute nd. by V. Ya. Yuryev NAAS, have high stable grain yield in combination with a high starch yield, and as a result with a high theoretical ethanol yield, that provides to winter rye competitiveness among the other alternative crops for bioethanol production.

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