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Impact of Weather Conditions and Farming Systems on Size Distribution of Starch Granules and Flour Yield of Winter Wheat

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Abstract: The size distribution of wheat-grain starch granules has an impact on the yield of fine flour. The aim of the study was to compare the impact of conventional (mineral fertilizers, pesticides) and organic farming treatments (cover crops, composted cattle manure) on (i) the size distribution of starch granules, (ii) the level of the first break whole and fine flour yield. The grain samples of winter wheat cv Fredis were taken from a long-term field crop rotation experiment established in 2008 at the Estonian University of Life Sciences in Tartu County (58°22′ N, 26°40′ E) on *Stagnic Luvisol* soil. The weather conditions during the grain filling period of winter wheat had a strong impact ($p < 0.001$) on the grain starch granule size distribution. The proportion of starch granules with a smaller diameter (C-type granules) was higher in years with a longer grain filling period. The size distribution of starch granules was not influenced by farming system. The increased proportion of C-type granules increased the fine flour yield significantly. Fertilisation with organic manure and twice with mineral nitrogen increased significantly the mean diameter value of different starch granules.

Keywords: organic; conventional farming; whole; fine flour yield

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1. Introduction

Wheat is one of the most important cereals for human and livestock consumption, with 75–78% of the total production being consumed by humans [1]. The physical and compositional properties of wheat grains determine the quality of the end product. Wheat has two textural classes i.e., soft and hard [2] and in the Baltic Sea region it is soft wheat that is mostly cultivated. The texture of winter wheat grains is affected by several factors, such as the farming system, variety, locality and the weather conditions in the post-hibernation period [3]. Growing winter wheat has become more popular among farmers with different crop production systems in Estonia (organic and conventional). The organic farming system has been adapted for many climate zones and local conditions. However, nitrogen (N) fertilisation management and irregular availability of N due to factors influencing mineralisation in the soil, are two of the biggest challenges for organic farming [4]. In the conventional farming system, the N from mineral fertilizers is easily available to plants in their early stages of development, which results in the much higher grain yield [5]. Xue et al. [6] found that late mineral N fertilizers as additional N or split from the basal N at late boot stage or heading in the form of nitrate-N or urea improved loaf volume of wheat flour by increasing grain protein concentration and altering its composition. Rossini et al. [7] said that at the same N rate, grain yield and quality were markedly higher using mineral N as opposed to organic N.

During grain development, the differentiated endosperm contains four major cell types: the cells of the region surrounding the embryo, transfer cells, aleurone layer, and starchy endosperm. The starchy endosperm cells gradually accumulate reserves (mainly proteins and starch) during development, and are filled with amyloplasts and protein bodies at maturity. Jane [8]. Previous investigations have found that variations in starch granule distribution are significantly correlated with changes in starch pasting viscosity [9], dough mixing properties [10] and bread crumb structure [11]. Wheat endosperm has a trimodal distribution of starch granules, i.e., A-granules with lenticular shape (diameter 10–50 μm), B-granules with spherical shape (diameter 5–9.9 μm) and C-granules with irregular shape (diameter < 5 μm); [12]. The different sizes of the starch granules might be attributed to their time of formation during grain development [13]. A-granules are formed around 4–14 days post anthesis (DPA) when the endosperm is still actively dividing [14]. B-granules are initiated at about 10–16 DPA in stromules, and the small C-granules first appear about 21 DPA [12]. The irregular shape of C-granules might be due to their small size and tight packing in the seed. The results can be expressed as percentiles of diameter value of size distribution. For example, percentiles of 10, 50 and 90% are associated with the size of C-, B- and A-type granule diameter, respectively [15,16].

Li et al. [17] reported that N fertiliser application (combined with S fertiliser) is a good way to improve A- and B-type starch granule accumulation in the central endosperm tissue sections during the grain-filling stage. Xiong et al. [18] found that increased N fertilizer application mainly increased the numbers of small and decreased the numbers of large starch granules, but that the results varied in different regions of the wheat endosperm. Farming systems with different N management influence pre-anthesis above ground biomass formation and the post-anthesis grain filling period, i.e., the starch and photosynthetic carbon mobilisation from stems and leaf sheaths to developing reproductive tissues [19]. Besides the farming system, the post-anthesis environment such as water availability and temperature strongly influence seed size, thus it is important in defining physical properties such as screening and milling yield [20]. Tambussi et al. [21] said, that in C3 cereals, ear photosynthesis has been reported to provide photoassimilates especially during adverse environmental conditions.

The break flour yield from first-break roller milling was measured in this study. In modern flour milling wheat kernels are broken open using first-break roller mills [22]. This produces a wide range of particles from <200 μm to >2000 μm. After the first break stage, subsequent processes, typically four or more break passages, grading, purification, and eight or more reduction passages, mill and separate the endosperm and bran further. The higher the flour yield after the first break stage, the more economical the milling process [15,23]. Bechtel and Wilson [12] reported that flour yield is dependent on the proportion of endosperm in the wheat grain, which in turn is dependent on the farming system.

There is little research that explores the influence of farming systems and variable weather conditions on the size distribution of starch granules. The aim of the present study is to compare the impact of organic systems (cover crops, composted cattle manure) and conventional farming systems (mineral fertilizers, pesticides) on (i) the size distribution of starch granules, (ii) the level of the first break whole and fine flour yield. The hypotheses of this paper were: (1) the diameter of starch granules of winter wheat grains grown in organic conditions are smaller than that of granules grown in conventional conditions; (2) the starch granules size distribution depends on the length of grain filling period; (3) the farming system has an impact on first break fine flour yield.

2. Materials and Methods

2.1. Experiment Setup

The grain samples of winter wheat cv Fredis were taken from a long-term field crop rotation experiment to study the effects of organic and conventional systems on the size distribution of starch granules in grain and its impact on flour yield. The field experiment was established in 2008 at the Estonian University of Life Sciences Farm at Eerika, Tartu County (58°22′ N, 26°40′ E) on *Stagnic Luvisol* soil (sandy loam surface texture, C 1.38%, and N 0.13%, pH_{KCl} 6.0). During the rotation cycle five different crops followed each other in the order: barley (*Hordeum vulgare* L.) with undersown red clover, red clover (*Trifolium pratense* L.), winter wheat (*Triticum aestivum* L.), pea (*Pisum sativum* L.) and potato (*Solanum tuberosum* L.). The experiment was set up in a systematic block design with four replicates of each treatment and a plot size of 60 m^2 [24]. In the present study the data on winter wheat concerns the period 2013–2017.

These crops were treated using different farming systems: three treatments of organic and four treatments of conventional. The first organic treatment (Org 0) was a control, with symbiotically fixed atmospheric N_2 the only source of N, ploughed into the soil with the legume above-ground biomass (red clover and pea, i.e., twice during the crop cycle period). In the second organic treatment (Org I), in addition to legumes, cover crops were used as green manure in winter: after crops of winter wheat, potato and pea, the cover crops were a winter rye (*Secale cereale* L.) and winter oilseed rape (*Brassica napus* ssp. *oleifera var. biennis*) mixture, winter rye and winter oilseed rape were sown. Cover crops were ploughed into the soil as soon as possible after the snow melted in April. In the third organic treatment (Org II), fully composted cattle manure was added in early spring before winter wheat re-growth at a rate of 10 t ha^{-1}. The organic N amounts applied in 2013, 2014, 2015, 2016 and 2017 with manure were 54, 47, 46, 46 and 44 kg N ha^{-1}, respectively. The same data for phosphorus were 18, 14, 8, 11 and 13 kg P ha^{-1}, respectively, and for potassium 43, 42, 32, 17 and 29 kg K ha^{-1}, respectively.

The first conventional control treatment (N0) was the same as for the organic control treatment (Org 0). The other three conventional treatments had P–K fertilizers applied at sowing time at the rate of 25–95 kg P–K ha^{-1}. Amounts of P and K were similar in all treatments. The conventional treatment N50 had the mineral nitrogen fertilizer (NH_4NO_3) applied in early spring at the tillering phase of winter wheat, treatments N100 and N150 had N fertilizer twice—at tillering stage 50 and 100 kg N ha^{-1}, respectively, and at booting stage BBCH47 additionally 50 and 50 kg N ha^{-1}, respectively.

The tillage method in all treatments was mouldboard ploughing to a depth of 20 cm. The conventional systems were treated with several synthetic pesticides against weeds, diseases and pests one to four times during growth as required. In the organic systems, weed control after sowing and in the winter wheat field at the end of April was carried out by spring-tine harrowing. Development stages of winter wheat were determined every week by observation and using of BBCH-scale for cereals. Determination of the physiological maturity (PhM) of winter wheat was based on kernel water and dry matter [25]. The above ground biomass samples of wheat were taken from an area of 1 m^2. Samples were taken before harvest every year, from which the above ground biomass in dry matter (DM) were determined. Winter wheat was harvested with a Sampo combine on 12 August 2013, 4 August 2014, 12 August 2015, 26 July 2016 and 28 August 2017 (moisture content of kernels was 20–28%).

2.2. Chemical Analysis

Well composted manure was used in the trial. The total nitrogen (N_{tot}) content of oven-dried manure and grain samples were determined by the dry combustion method on a varioMAX CNS elemental analyzer (ELEMENTAR, Langenselbold, Germany) [26]. Acid digestion by sulphuric acid solution was used to determine cattle manure P_{tot} and K_{tot} concentrations.

2.3. The Size Distribution of Starch Granules

The size distribution of starch granules was determined in winter wheat grain endosperm using a Malvern Mastersuzer 3000 analyzer (Malvern Instruments Ltd., Malvern, UK). A standard protocol was used [27] to separate the starch from 100 mg of material, which was taken from each treatment. The starch suspension was used for laser diffraction analysis. Particle size analysis was conducted as described by Li et al. [28] and Tanaka et al. [29]. About 0.1 mL of starch was suspended with 1 mL of reverse osmosis water (Grade 2, conductivity 5-6 µS/cm) in 2 mL Eppendorf tubes and briefly vortexed prior to transfer into the particle size distribution analyser's dispersion tank containing the same origin reverse osmosis water. The statistics of the distribution are calculated from the results using the volume derived diameters Dv—an internationally agreed method of defining the mean and other measurments of particle size. Dv(50), Dv(10) and Dv(90) are standard percentile readings from the measured size distribution.

2.4. Yield of Wheat Flour

The yield of wheat flour was measured in four trial years. In 2016 the flour yield was not determined because the winter wheat crop (2015/2016) failed and only a small amount of grain was available for milling. The grain samples of 1000 g per plot were tempered at 140 g kg^{-1} moisture and were milled with a laboratory mill LM 3100 (Perten Instruments, Hägersten, Sweden, 2018), after which the flour was sieved into three fractions: bran and shorts (sieve PA-47GG, SEFAR NYTAL PA, Retsch, Haan, Germany) particle size over 375 µm, coarse flour (sieve PA-72GG, SEFAR NYTAL PA) with particle size of 224–375 µm and fine flour with particle size below 224 µm. Whole flour yield was calculated as the sum of coarse and fine flour (particle size < 375 µm).

2.5. Meteorological Data

Meteorological data of the post-hibernation vegetation period in 2013-2017 were collected from a meteorological station approximately 1 km from the trial site (Table 1).

Table 1. Monthly average temperature (°C) and total precipitation (mm) in 2013–2017 compared with the long-term average (1969–2017).

Month	Temperature, °C *					
	2013	**2014**	**2015**	**2016**	**2017**	**1969–2017 ****
April	3.5	6.5	5.4	6.1	3.4	4.8
May	14.8	11.9	10.3	14.0	10.2	11.4
June	18.2	13.4	14.3	15.9	14	15.4
July	17.8	19.9	15.7	17.8	15.9	17.5
August	16.9	16.8	17.0	16.1	16.8	16.2
April–August	14.2	13.7	12.5	14.0	12.1	13.1
	Precipitation, mm *					
April	17	13	51	50	52	29
May	61	84	60	2	16	56
June	52	104	40	125	94	78
July	63	71	62	82	61	70
August	75	113	42	42	106	88
April–August	268	384	251	301	329	321

* data from Eerika meteorological station; ** long term average of 1969–2017.

Weather conditions during the post-hibernation period had a strong effect on the above ground biomass and grain yield quality formation of winter wheat. The length of the post-hibernation vegetation period depended on the date that snow melting in April. Later snowfall in 2013 and 2017 and lower temperature values during the vegetation period in 2017 delayed harvest of winter wheat in that year. The regrowth of winter wheat, after the snow melted, started in 2013 and 2017 at 16 of April and 1 of May, respectively, which was 5–25 days later than of other trial years (2014–2016). In 2015 the mean temperature of May was 1.1 °C lower than the long-term average, but the precipitation was sufficient, which facilitated the tillering and growth of above ground biomass of winter wheat. In 2015 lower temperatures and regular precipitation during the post-hibernation period resulted in a record grain yield of winter wheat. The most unfavorable weather conditions for grain yield formation were in 2016, when the amount of precipitation in May was only 2 mm and temperature data during the post-hibernation vegetation period were higher than the long-term average (Table 1). However, this article does not deal with the grain yield of winter wheat.

Growing degree days (GDD) were used to characterise the impact of weather conditions on starch granule size distribution. GDD is given as the mean daily temperature above a 5 °C base temperature accumulated on a daily basis over a period of flowering-physiological maturity (BBCH65-PhM).

2.6. Statisticsal Analysis

Correlation, factorial analyses of variance (ANOVA), descriptive analysis and two-factor ANOVA were used to test the effect of farming systems and experimental year on granules size of distribution and flour yield of winter wheat. The means are presented with their standard errors (±SE). The level of statistical significance was set at $p < 0.05$ if not indicated otherwise.

3. Results

3.1. The Factors Influencing the Size of Starch Granules

The size distribution of starch granules was significantly related to several factors studied in this field trial, such as fertilisation with organic or mineral N fertilisers ($p < 0.001$), weather conditions ($p < 0.001$), biomass yield at flowering stage of wheat (BBCH65; $p < 0.01$) and length of period from BBCH65 up to physiological maturity (PhM; $p < 0.001$; Table 2).

Table 2. Correlation between starch granules size distribution and several factors studied in this trial.

Factors	Dv(10)	Dv(50)	Dv(90)
Temperature *; n = 105	−0.39 ***	−0.37 ***	−0.26 **
Precipitation *; n = 105	ns	ns	−0.26 **
Length of period BBCH65-PhM; n = 112	−0.54 ***	−0.52 ***	−0.40 ***
N amount (treatment); n = 105	0.20 *	0.19 *	0.19 *
Farming system; n = 105	ns	ns	ns
Biomass of wheat at BBCH65; n = 112	−0.27 **	−0.26 **	ns
Fine flour yield; n = 56	−0.40 **	−0.27 *	−0.27 *
Whole flour yield; n = 56	−0.31 *	−0.31 *	−0.29 *

* Mean temperature and sum of precipitation is for grain filling period; *, **, ***—these signs indicate the statistical significance at $p < 0.05$, 0.01 and 0.001 level.

The proportion of variation of Dv(10), Dv(50) and Dv(90) were for weather conditions and farming system 38 and 18%, 24 and 24%, 18 and 18%, respectively. The same data for interaction between these two factors were 44, 24 and 63%, respectively (data not shown).

3.1.1. Impact of Weather Conditions on Starch Granule Size Distribution

The size distribution of starch granules was most influenced by the length of the grain filling period, i.e., the period of BBCH65-PhM, which in turn was positively correlated with the mean temperature and GDD values in this period ($r = 0.84$; $p < 0.001$). In 2013 and 2017 the period of BBCH65-PhM was 3-5 days longer and therefore the GDD values were 40-168 °C higher than in other trial years (Table 3). In 2013 and 2017 the mean temperature values in the grain filling period were higher (ranged between 16.2–18 °C), whereas in other years the fluctuation was between 14.5–15.7 °C.

The value of GDD in 2016 was influenced by much higher amounts of precipitation, which was 197 mm (in other years it ranged between 67–115 mm). In 2013 and 2017 the starch granule diameter of Dv(10), Dv(50) and Dv(90) was up to 17, 29 and 33% smaller than in 2014–2016, except for Dv(90) 2016 vs. 2013 (Table 4).

Table 3. Accumulation of growing degree days (GDD; °C) in 2013–2017 and length of grain filling period (from flowering up to physiological maturity).

Parameter	Years				
	2013	2014	2015	2016	2017
	Dates of Flowering (BBCH65) and Physiological Maturity (PhM)				
BBCH65	5.06	10.06	15.06	4.06	29.06
PhM	15.07	16.07	20.07	11.07	7.08
BBCH65-PhM, days	40	36	35	37	40
GDD for period of BBCH65-PhM, °C	519	351	358	408	448

Table 4. Mean values (±SE) of starch granule size distribution over farming system treatments and experimental years.

Year	Dv(10), µm **	Dv(50), µm	Dv(90), µm
2013	2.85 ± 0.05 b *	6.63 ± 0.29 bc	17.80 ± 1.54 ab
2014	3.13 ± 0.06 a	7.86 ± 0.30 ab	20.40 ± 1.04 ab
2015	3.05 ± 0.03 a	8.15 ± 0.35 a	22.61 ± 0.88 a
2016	3.12 ± 0.04 a	7.08 ± 0.24 abc	17.01 ± 0.67 b
2017	2.70 ± 0.05 b	6.25 ± 0.20 c	16.77 ± 0.99 b

* different letters in the same column denote a significant difference (Fisher LSD test, $p < 0.05$). ** Dv(10), Dv(50), Dv(90)—the size of particle in microns below which 10, 50 and 90% of the sample, respectively, lies.

3.1.2. Impact of Organic and Mineral N on Starch Granule Size Distribution

The starch granule diameter was significantly influenced by different doses of organic and mineral N applied in organic and conventional treatments, respectively. In the organic system the use of composted cattle manure (treatment Org II) increased the values of Dv(10), Dv(50) and Dv(90) up to 15, 23 and 31%, respectively, in comparison with other organic treatments (Table 5).

Table 5. Mean values (±SE) of starch granule size distribution over experimental years in the comparison of farming system treatments.

Treatment	Dv(10), µm **	Dv(50), µm	Dv(90), µm
Organic			
Org 0	2.85 ± 0.07 b *	6.76 ± 0.36 abc	18.15 ± 1.59 ab
Org I	2.96 ± 0.05 b	7.14 ± 0.38 abc	17.83 ± 1.50 ab
Org II	3.22 ± 0.06 a	8.03 ± 0.28 a	22.77 ± 1.04 a
Conventional			
N0	2.91 ± 0.05 b	6.26 ± 0.11 c	15.94 ± 0.82 b
N50	2.86 ± 0.05 b	6.43 ± 0.18 cb	16.90 ± 0.70 b
N100	2.97 ± 0.07 ab	7.49 ± 0.40 ab	19.93 ± 1.22 ab
N150	3.04 ± 0.07 ab	8.23 ± 0.49 a	20.94 ± 1.70 ab

* Different letters in the same column denote a significant difference (Fisher LSD test, $p < 0.05$). ** Dv(10), Dv(50), Dv(90)—the diameter of particle in microns below which 10, 50 and 90% of the sample, respectively, lies. Org 0—control treatment of organic crop production system; Org I—organic treatment with cover crops; Org II—organic treatment with cover crops and composted cattle manure; N0—control treatment of conventional system; N50, N100 and N150—conventional treatment with mineral nitrogen applied 50, 100 and 150 kg N ha^{-1}, respectively.

In the conventional system the higher amounts of mineral N also increased the starch granule diameter and values of Dv(10), Dv(50) and Dv(90). The increase was up to 8, 30 and 33%, respectively, compared to the control of the conventional system although only Dv(50) statistically significant. However, the mean diameter of starch granules for the organic system was statistically equal with the mean diameter of the conventional system.

Fertilising with organic and mineral N influenced the biomass yield formation of winter wheat, which in turn influenced the diameter of starch granules. The correlation between starch granule diameter and above ground biomass yield of winter wheat at BBCH65 stage was negative (Table 2). Mean biomass yield over trial years obtained from fertilised treatments of the conventional system ranged between 10.6-12.6 t ha^{-1}, which was 19-39% higher than the organic treatments (data not shown).

3.2. The Flour Yield

According to the ANOVA, the whole flour yield of winter wheat cv Fredis (flour particle size 0-375 and 0-224 μm, respectively) was significantly influenced by weather conditions (65%) and farming system treatments (9%). The influence of the same factors on the fine flour yield was 69% and 7%, respectively. But, the mean whole and fine flour yield over treatments of the organic system was statistically equal with the mean flour yield of the conventional system. In 2013 and 2017 the mean yield of whole and fine flour over treatments was 3-6% and 8-23% higher, respectively, than in 2014-2015 (Table 6). The ratio of whole flour yield to bran and shorts was significantly affected by trial year weather conditions (the proportion of variation was 57%).

Table 6. Mean values (±SE) of winter wheat flour yield over farming system treatments and experimental years.

Year	Fine Flour Yield (g kg^{-1})	Whole Flour Yield (g kg^{-1})	Bran and Shorts (g kg^{-1})	Ratio of Whole Flour Yield to Bran
2013	483 ± 10 bc *	758 ± 3 a	204 ± 2 b	3.72 ± 0.06 a
2014	440 ± 6 d	725 ± 3 b	229 ± 3 a	3.18 ± 0.05 b
2015	459 ± 9 cd	729 ± 3 b	229 ± 2 a	3.19 ± 0.05 b
2017	554 ± 7 a	760 ± 4 a	213 ± 8 b	3.59 ± 0.08 a

* Different letters in the same column denote a significant difference (Fisher LSD test, $p < 0.05$).

The influence of farming system treatments on the fine flour yield was significant according to ANOVA ($p < 0.01$), but the effect was small (the proportion of variation was only 7%) and according to descriptive statistics the effect of treatments was insignificant. Fine flour yield obtained from organic system treatments was between 410-590 g per 1 kg of kernels and from conventional system treatments between 398-584 g per 1 kg of kernels, whereas higher values were obtained from treatments without N or with smaller amounts of N. As mean grain yield over treatments and trial years in this field experiment was 26–36% higher in conventional than that in the organic system (data not shown), the fine flour yield per hectare was also higher in the conventional system. Fine flour yield in organic and conventional treatments ranged between 1507-2206 and 1873-2757 kg ha^{-1}, respectively. The yield of whole and fine flour was significantly influenced by the size of starch granules, and the diameter of starch granules was negatively correlated with flour yield (Table 2).

4. Discussion

In Estonia (by the Baltic Sea), wheat is subjected to ever-changing weather conditions, so the grain yield and quality is seasonally variable as already demonstrated in other wheat producing countries [7,30–33].

The baking quality of wheat flour is better when the number of large starch granules (A-type) is higher than of small (B- and C-type) resulting in higher loaf volumes. This is influenced by the composition of starch granule structure, i.e., the size and ratio of amylose and amylopectine molecules in starch granules [34].

The results of our study showed that the size distribution of starch granules was significantly influenced by weather conditions during the post-anthesis grain filling period of winter wheat. The diameter of starch granules within which 10, 50 and 90% of samples lay, ranged in different trial years between 2.7-3.2, 6.1-8.2 and 15.8-23.5 µm, respectively. The size of starch granules below which 10% of sample lay Dv(10) was significantly smaller ($p < 0.01$) in 2013 and 2017 (Table 2), when the mean temperature development stage of BBCH65 up to PhM was 0.5-3.5 °C higher and 3–5 days longer than in other trial years. Lower values of Dv(10) were probably caused by a greater proportion of small (C-type) granules, which are formed during a later phase of the grain filling period. These findings are in agreement with previous studies [35,36]. Hurkman et al. [35] reported that a shortened grain filling period decreases the levels of enzymes involved in starch biosynthesis. Our results showed that the length of the grain filling period was negatively correlated with mean temperature and GDD values in this period. Acevedo et al. [36] found that mean temperature did not influence significantly the grain filling duration. Heat stress during the grain filling period mainly affects assimilate availability, translocation of photo-synthates to the grain and starch synthesis and deposition in the developing grain. The influence of weather conditions on the length of the grain filling period needs further investigation. The influence of precipitation was insignificant.

Fertilising with different doses of N from different farming systems had a significant effect on starch granule diameter, which is in agreement with Li et al. [17] findings. Higher diameter values of Dv(10), Dv(50) and Dv(90) were obtained from treatments Org II, N100 and N150. In Org II treatments the well composted cattle manure was applied at the tillering stage for winter wheat (in Estonian conditions, the first decade of May) and it's likely that mineralization of N and subsequent uptake by plants took place in June and July (flowering and grain filling period of winter wheat). The conventional farming system treatments N100 and N150 were fertilized with mineral N twice (second time at BBCH 47 stage of winter wheat), which probably results in higher diameter values of starch granules.

In this study the size of starch granules below which 10 and 50% of sample lay was significantly influenced by above ground biomass yield of winter wheat (negative correlation; Table 2). In conventional farming system the fertilising with mineral N resulted in up to 1.6 times higher biomass yield of winter wheat at anthesis (BBCH65) than that in the organic system. Plant stems and leaf sheaths are sites of temporary carbon storage that can be remobilized to reproductive tissues, significantly contributing to grain filling in later developmental stages [19]. However, Smidansky et al. [37] found that in the case of cereals, higher biomass yield increases grain yield due to enhanced seed number and survival of the seeds (i.e., reduced embryo abortion) rather than to increased starch per seed.

The flour yield and quality obtained from wheat grain depends on the size of starch granules [15], crop production system and proportion of grain endosperm [12,38]. In this study the yield of whole and fine flour obtained after the first break roller milling was mostly influenced by the weather conditions of the trial years and interaction between weather conditions and farming systems. Flour extraction was higher in years with longer post-anthesis grain filling period of winter wheat (in 2013 and 2017) and negatively correlated with starch granule size. A smaller diameter of starch granules indicates a larger proportion of smaller types of granules, higher ratio of whole flour yield to bran and higher flour yield. These conclusions are similar to the results of Edwards [15]. It may be noted that meteorologists predict the prolongation of plant growth period in the Baltic Sea region.

5. Conclusions

The weather conditions during the grain filling period of winter wheat cv Fredis had a strong impact ($p < 0.001$) on grain starch granule size distribution. The size of starch granules was not influenced by farming system (first hypothesis). Fertilization with organic manure and twice with mineral nitrogen during the growing season increased significantly the mean diameter value of different starch granules. The mean diameter of starch granules was smaller in trial years with a longer grain filling period because of higher proportion of C-type granules in these years (second hypothesis). The flour yield of winter wheat cv Fredis kernels was influenced by the size distribution of starch granules, whereas the increased proportion of granules with a smaller diameter (C-type granules) increased the fine flour yield significantly. The impact of farming systems on fine flour yield was not significant (the third hypothesis).

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