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WHEAT – A CHALLENGING SUBSTRATE FOR STARCH PRODUCTION[#]

Abstract

In contrast to the world-wide given situation for maize as the main substrate in starch isolation, wheat gains an advantageous position in the European starch industry although technical starch yield cannot compete fully material prices. Its remarkable position profits also from wheat gluten as valuable by-product. Further indication for rising preference can be seen in the installation of new processing capacities in Europe. However, the economic situation of wheat starch production follows unavoidable fluctuations of wheat gluten markets. Political decisions play an important role, too.

The challenging situation connected with wheat as substrate for starch extraction is result of developments in equipment and remodelling of technology. The most important contribution consisted in an obvious shift of the relation of water to flour used for flour/water mixture preparation, starch and gluten extraction, and refining. This was initialised mainly by the introduction of separation techniques using centrifugal principles. With respect to limited availability of water and increasing costs for waste water treatment reduction of water supply is a steady target.

In close connection to developments in separation technology wheat and wheat flour should gain extended attraction. Published standards are limited and reveal at most characteristics oriented to the Martin process. With respect to recent developments in technology, alternative testing procedures have been proposed. Results demonstrate the suitability and specificity of the „Mixer method", a procedure adapted to flour/water relations in centrifugal separation. But, the time consuming procedure restricts general application. With respect to characteristics describing substrate properties, parameters of conventional wheat quality evaluation systems are measured additionally and assigned to quantities of the mixer method. An extended data base is expected to provide with measures to select the most suitable system for classification of wheat grain and wheat flour.

After all, the outlook should not omit to mention developments in conventional breeding and genetic engineering that will allow to affect starch granule characteristics, molecular structure and composition of wheat starch offering promising prospects in functionality and application of wheat starch.

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[#] *Publ. No.: 7178 of the Federal Center for Cereal, Potato and Lipid Research, Detmold Münster.*

Introduction – policy and the market

In a recently published review [1] starch policy in the European Community was sketched by its measures and institutional framework. Export refunds (to compete at the world market) and import duties (to repel starch produced in third world countries) were indicated as main measures for the Communities successful activity. These conventional instruments in foreign trade are completed by production refunds given to industrial producers utilising internally manufactured starch in particular in the non-food sector. This system allowed the European starch industry to develop a very strong position on the world market.

A world wide actual collection and evaluation of starch production is extremely difficult to establish. In particular reliable data concerning regions and specific starch substrates are scarcely available. Starch production itself is still characterised by a dominating role of maize which stands on Community level for approximately 50% of the produced starch; a position that is not any longer invincible. Wheat and potatoes are going on to change relevant shares. Since EU potato starch production has been limited by introduction of fixed quotas for all member countries further development is expected to contribute exclusively to increases in the corresponding wheat starch portion. The variability in wheat starch production given within member states can be documented well by their position in an estimate for 1999 [2]. During the last decade the French wheat starch industry grew extraordinarily and leads indubitably with approximately $760 \cdot 10^3$ t, while Germany and Netherlands lie equalised at second and third position with approximately $360 \cdot 10^3$ t. The aforesaid countries dominate European starch production with a share of 75% (Tab. 1). In contrast, the Eastern European countries including Russia are indicated to produce just $113 \cdot 10^3$ t. In comparison to the position of the main wheat starch producers within the EU the generally known production capacity within these countries is very small and potential changes depend highly on economic and to some extent also on political developments (Tab. 2). A comparison of production figures within different regions of the world's production ($3270 \cdot 10^3$ t) documents again the role of the European Community (60%) in having the control over the world market (Tab. 3).

Which factors did promote the increased utilisation of wheat in starch production? Although according to Wintzer et al. [3] net production costs for wheat starch are higher ($430\ €\cdot t^{-1}$) than for maize starch (approx. $380\ €\cdot t^{-1}$) drastic reductions in substrate prices evaluated on basis of net costs [4] as well as close neighbourhood of wheat production and processing were beneficial factors. Together with a slightly higher processing margin for wheat starch and a lower procurement price for wheat produced in the European Community also Entwistle et al. [5] found small advantages for utilisation of this crop in the UK.

Table 1

Estimates for wheat starch production in the European Community in 1999.

Country	Production [x 10^3 t]
France	761.2
Germany	357.0
Netherlands	357.0
United Kingdom	199.5
Belgium	178.5
Italy	52.5
Finland	31.5
Sweden	24.2
Total	1963.4

Table 2

Estimates for wheat starch production in Eastern Europe in 1999.

Country	Production [x 10^3 t]
Yugoslavia	31.5
Poland	26.2
Czech Republic	16.8
Hungary	13.1
Russia	10.5
Slovak Republic	7.9
Romania	5.2
Slovenia	2.1
Total	113.3

Table 3

Estimates for world-wide wheat starch production in 1999 (x 10^3 t).

Production in total	3270
European Community (8 of 15 countries)	1963
Eastern Europe	113
North and South America (USA, Canada, Mexico, Argentina)	596
ASEAN and Pacific Area	570

To deal with wheat starch without mentioning the role of wheat gluten is politically and economically short-minded since gluten was always an important co-product in the economical evaluation of wheat starch production. However, with regard to relationships between US administration and the European Commission the controversy on restriction of gluten imports to the US (a quota frozen to $25 \cdot 10^3$ t annually since 30 May 1998) just now produces further unpleasant conditions in mutual relationships. According to newspapers it is planned to divide the existing quota into quarterly parts. Authorities of the European Commission, in contrast, insist on removal of existing restrictions [6].

Developments in equipment and technology

Equipment

A comprehensive overview of recent technological developments in the production of wheat starch has been presented in 1997 by Meuser [7] when reporting the extraordinary progress in starch separation from wheat flour by the application of centrifugal forces. In the early stage of separation of wheat flour components 3-phase decanters represented the principle machines which delivered an overflow (light phase) containing high shares of pentosans, a nozzle phase (middle phase) consisting of few pentosans, high portions of B starch, gluten and fibre and a concentrate containing nearly the whole share of A starch and some B starch and fibres. The early and very effective separation of flour into its components was prerequisite for economically improved recovery of starch and vital gluten, and divers by-products. Centrifugal forces were used successfully, too, in replacing static separation procedures of starch refining. Finally, nozzle separators of the 3-phase type were the respective machines that allowed also remarkable progress in formation of economically enhanced process operations, in particular in reduced needs of process water for A starch washing and a high-yielded recovery of co- and by-products [8].

Further focus was given meanwhile to drainage of refined wheat starch by means of pressure filtration. Since its first reference [7] interesting solutions were reported [9-11] that are basis for the following presentation.

Pressure filtration

Vacuum drum filters or discontinuously working peeler centrifuges allow to reach a minimum water content of 36 to 40% in drainage of starch suspensions [12]. It's state of art that free water of this amounts results in thixotropic flow behaviour of starch cakes and impedes their transportation [7]. Based on successful drainage of mineral suspensions [13] pressure filtration has been applied also to starch de-watering, in particular with such starch suspensions where water removal remains critical. With wheat starch that contains in general a serious amount of fine granules and that tends to produce difficulties in this respect cake formation and drainage can be drastically accelerated [7]. For native wheat A starch as well as for native corn starch the range of available water reduction was reported to reach 33 to 35% with systems of different design [9-11]. Relevant systems installed in starch plants are pressure drum filters [9, 10] and membrane filter presses [11].

In case of pressure drum filters the system consists of a filter drum covered with a specific filter cloth inside a pressure vessel and a discharge for release of drained starch (Fig. 1). Reported pressure levels can range from 1 to 6 bar. Practical working conditions are pressure levels of approximately 3 to 3.5 bar, drum rotation speeds from 1.2 to 1.6 min^{-1} and a specific starch throughput in the range of 450 to 800 $\text{kg}\cdot \text{m}^{-2}\cdot\text{h}^{-1}$. Installed filtration surfaces are given with 10 to 17 m^2 [9, 10].

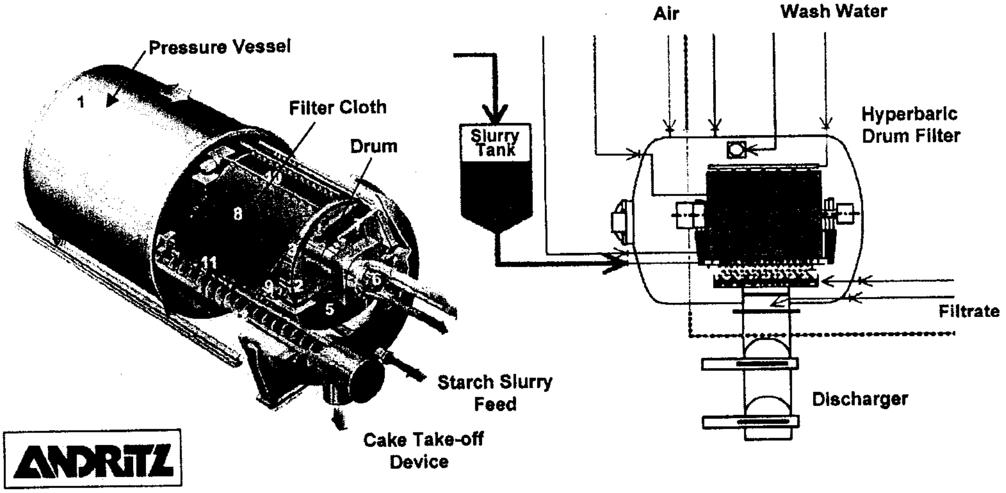


Fig. 1. Pressure drum filter system for starch slurry drainage.

A membrane filter press was presented as so-called diaphragm pressing system (Fig. 2). The filter consists of multiple filter chambers each of 45 to 60 mm height. A continuous filter cloth supported by propylene latticing is running through all filter chambers equipped with 4 to 5 mm thick rubber diaphragms by which the flow of starch suspension, filtrate, wash water and air are directed alternately. Pressure that can rise up to 16 bar is applied via the diaphragm by water. Additional drainage can be induced by blowing air through the pressed filter cake. Final cake water contents can be reduced to 33% for native wheat starch. The specific filtration rate is reported to reach 240 $\text{kg}\cdot\text{m}^{-2}\cdot\text{h}^{-1}$ and the maximum capacity to be 3.4 t. An almost continuous process is reached by a fully automated process operation.

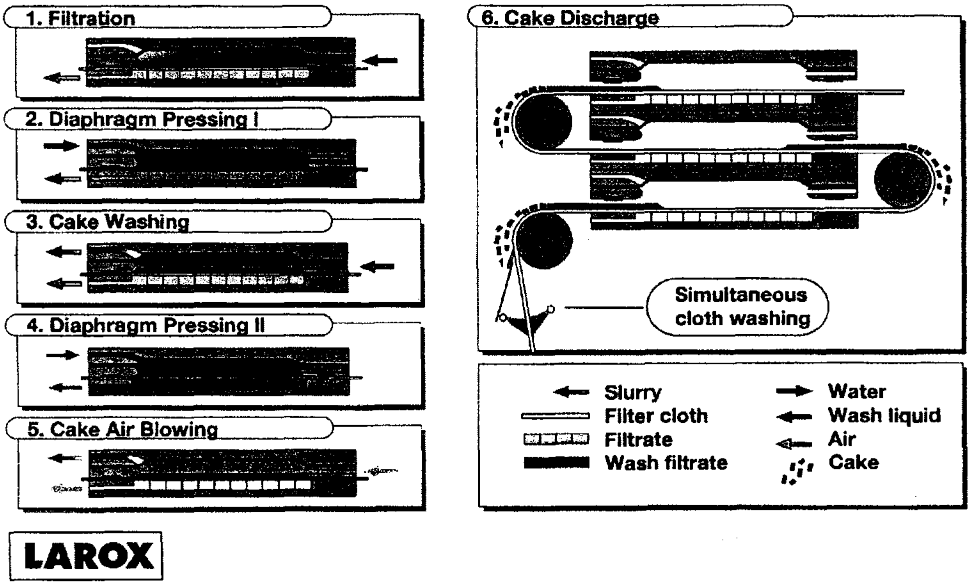


Fig. 2. Membrane pressure filtration system for starch slurry drainage with cake washing.

Technology

In 1999 Maningat and Bassi [2] presented an excellent overview about the state of art in wheat starch production. They reviewed in particular the situation in North America, where the Modified Martin Process, the Hydrocyclone Process and the Alfa-Laval/Raisio Process are standard procedures in industry. In contrast, more recent technology based on the HD (high pressure disintegration) or the Tricanter® Process were indicated as predominant in European industry. Driving force in process development was the reduction of fresh water use in relation to wheat flour utilised for preparation of a dough or batter and following extraction/separation of starch, gluten, fibres and further flour components (Tab. 4). While for the Martin process in its original form as well as for the batter process a water/flour relation of 15:1 was characteristic, technological improvements in both processes concerning in particular recycling of process water led finally to a ratio of 6:1. A concentrated flour-water system similar a baker's bread dough consisting of 1 part flour and 0.6 parts water was prepared initially for extraction. In other process proposals which used hydrocyclones or decanters as primary separation systems further reductions in the flour/water ratio to 4.5:1 and 4:1 were reported. More recent developments like the HD process which stands for mechanical disintegration of suspended flour particles under application of high pressure in a specific valve and/or decanter processes allowed ratios of 3:1 or 2.5 to 2:1.

Maningat and Bassi [2] described the main important starch extraction processes. Their principles should be recalled in the following.

Table 4

Water/flour ratios applied in wheat starch production.

Process	Ratio
Martin Process	15 : 1
Modified Martin Process	6 : 1
Batter Process	5-7 : 1
Hydrocyclone Process	4-5 : 1
Decanter Process	4 : 1
HD Process	3-2 : 1

Modified Martin Process

In order to satisfy requirements of reduced fresh water consumption and to adapt equipment to recent standards in efficient starch/gluten separation the traditional Martin Process underwent improvements resulting finally in a process represented by a scheme (Fig. 3) of the central part of the Modified Martin Process [2]. Conventionally

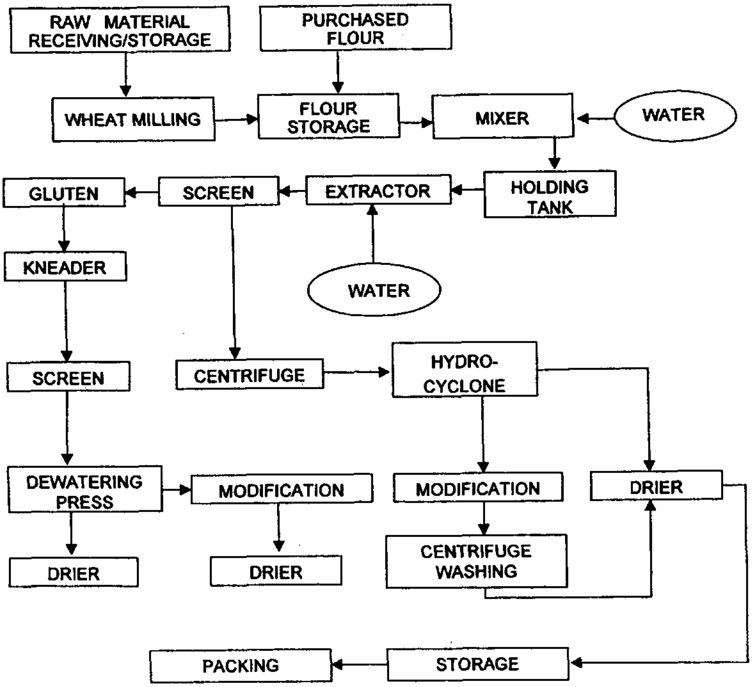


Fig. 3. Reduced schematic flow diagram of the modified Martin process [2].

or short milled flour is mixed with water (temperature = 32°C) in a continuous dough mixer in typical relations of 1.2:1 representing a dry substance content of approximately 47%. For complete hydration the produced cohesive dough undergoes a "rest". Then it is vigorously mixed and treated with turbulent agitation for quick gluten and starch separation which finally occurs in a long, slanted, hollow, rotating cylinder equipped with a 40 mesh stainless steel screen. Gluten is processed further in conventional manner to vital gluten or gluten products while the starch slurry is purified by sieving, centrifugation for B starch separation and hydrocyclone processing.

Hydrocyclone Process

Based on proposals of Verberne and Zwitserloot [15, 16] traditional processes (i.e. the Modified Martin Process) were modernised again by the use of hydrocyclones for gluten/starch separation (Fig. 4). After the continuous dough mixer the dough is allowed to mature for 10 to 20 min and then diluted into a homogenous suspension. Via a multistage hydrocyclone system where spontaneous gluten agglomeration occurs starch and gluten are separated according to their density difference. B starch and fibres are removed from gluten prior to flash drying. The starch slurry goes through a multistage hydrocyclone system for refinement and concentration and is finally dried after passing screens (75 and 50 µm for fine fibre removal).

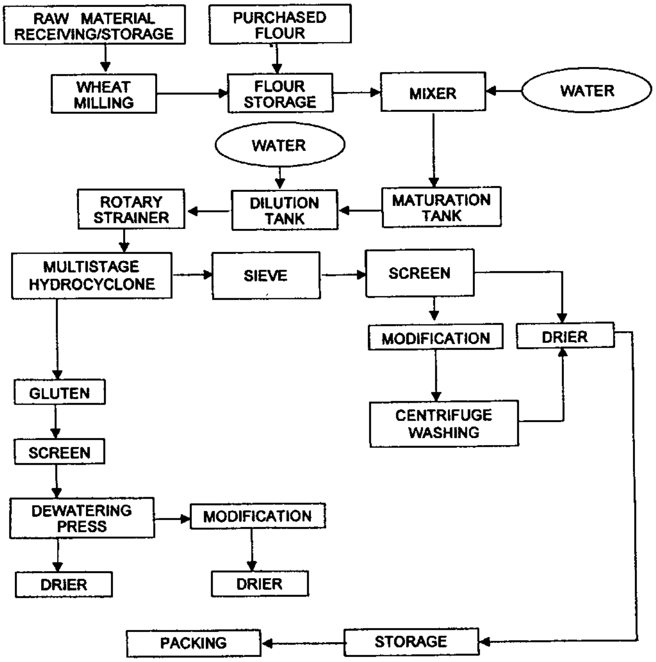


Fig. 4. Reduced schematic flow diagram of the hydrocyclone process [2].

Alfa-Laval/Raisio Process

In contrast to preceding described procedures the Alfa-Laval/Raisio Process (Fig. 5) uses a thick batter that passes a special disc type disintegrator for homogenisation. Starch and protein are then separated in a decanter type centrifuge. The resulting starch fraction that contains about 1% protein is further purified with screens for fine fibre removal and in two stages washed and concentrated in decanters. In the protein containing fraction (about 40% protein) gluten is developed by low-speed agitation via maturation. Aggregation of gluten particles into lumps is initialised in a disc type disintegrator which allows then separation of starch and fibre material by screening and succeeding drying to achieve vital gluten. From the filtrate of gluten screening all B starch as well as residues of A starch being present are recovered by decanting. A starch is further refined and B starch is dried after concentration [16].

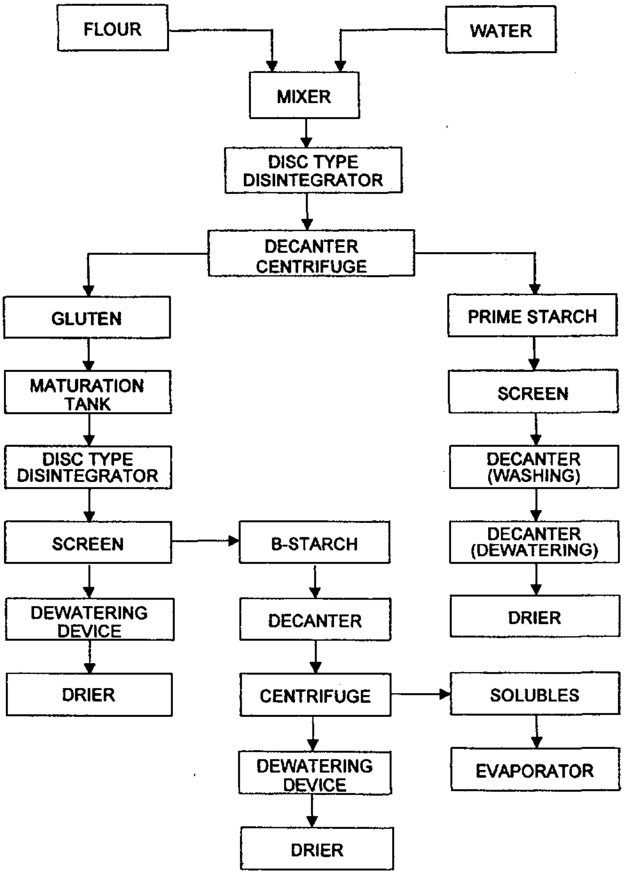


Fig. 5. Schematic flow diagram of the Alfa-Laval/Raisio process [2].

Westfalia Centrifuge/HD or Tricanter® Process

Decisive in modern process technology, however, was not only a very effective water regime during purification steps for wheat components but also a substantial improvement in initial flour hydration and subsequent separation of components from each other in early stages of selected process unit operations. In recent processes [7, 8] centrifugal techniques followed segregation of flour into starch, gluten, fibres and pentosans. A method described as very effective in splitting flour components was high pressure disintegration where shearing forces, friction and cavitation produced the disruption of the tissue within the specific valve of the homogenizer. This technique was successfully taken over from studies of maize starch extraction after pre-treatment of ground, de-germinated maize [17]. Extrication of starch granules, soluble proteins and pentosans from the hydrated flour protein matrix produces the prerequisite for aggregation of protein bodies to voluminous lumps. Because of their still lower density (approx. 1.1) compared to starch (approx. 1.5) they leave decanters with the middle phase of 3-phase decanters when transportation to the concentrate site is successfully impeded. A decanter screw equipped with a sluice disc forms while transporting settled starch to the concentrate outlet a dynamically changing ring-like sediment that separates the feeding and separation zone from the concentrate (drainage) zone [8, 18].

The principal process exists in varied designs, i.e. Westfalia Centrifuge/HD Process, Flottweg Tricanter Process, Barr & Murphy Process, Decanter-Based Weipro Process [2, 15, 19]. At the very beginning a batter/dough similar to other processes is produced and then disintegrated under high shear of a homogenizer. This homogenate is then separated in the aforesaid 3-phase decanter into three destinct phases. The concentrate consists almost entirely of A starch (less than 1% protein) which is refined to commercial quality wheat starch in multistage hydrocyclone units or in multistage 3-phase nozzle separators. The middle phase that consists of gluten, B starch and some fibre as well as the light phase having mainly pentosans and solubles are further separated, purified, concentrated and dried as described by Maningat and Bassi [2] or presented by Witt and Seiler [8].

Gluten drying

The effect of drying conditions on proteins in general is well known. Proteins undergo undesirable structural changes and loose their functional properties when treated under unfavourable conditions, for instance high drying temperatures. Wet wheat gluten is difficult to handle because of the visco-elastic properties and stickiness of this material. On the other hand, the preservation of these properties, in general indicated as vitality, makes the specific quality and value of carefully dried wheat gluten.

Leaving the refining step wet gluten exists in large sticky clots. To overcome the stickiness and to provide an adequate surface area for quick drying it is mixed with dry product to be chopped into small lumps; for instance, into particles with a diameter less than 1 cm. Coating the wet material with the dry one balances furthermore heat transfer from hot air as drying medium and enhances water evaporation. Thermal stresses on particles transported in the hot air stream of the dryer are thus reduced in an order that avoids for the most part product temperatures detrimental to the proteins. Nevertheless, as a matter of size differences and of initial water content particles reach final moisture content at different times and thus after passing the drying zone several times. On average, gluten particles pass through a dryer more than three times. Using an industrial dryer mill, some particles were found to pass the drying zone up to seven times [20].

Industrial gluten drying occurs in flash dryers. Mainly ring dryers but also dryer mills are used. In both systems wet gluten undergoes changes in its visco-elastic properties as a result of the hot air temperature, the mixing ratio of wet to dry material (i.e. dry matter content of the feed) and the average number of add-back cycles. According to recently presented investigations [20] the visco-elasticity of commercial gluten samples differed significantly between production plants as a result of applied drying procedures. In gluten samples dried under test conditions the effect of hot air temperature was pronounced as soon as product temperature surpassed 60°C. Temperatures above this level are regarded as responsible for denaturation of gluten proteins. Surpassing of this temperature limit could be distinctly observed in simulation of a second and third add-back cycle. Reduced dry matter content in the feed had so far a similar effect.

Developments concerning substrates and testing methods

For substrate selection two sets of specifications representing either grain or flour are dominating [21]. With respect to the Martin process which was for a long time the predominantly utilised technology good dough formation was of prime importance. To meet this requirement minimum wheat grain protein content (N•5.7) was fixed for 14.1 to 14.7% in substance. Specifications indicate furthermore a soft grain type, high starch quantity and limited enzyme activity (Tab. 5). Flour characteristics require an equivalent quality level but specify additionally upper limits for mineral content (Tab. 6). The ongoing demand on wheat gluten as valuable co-product affect still substrate selection in particular with protein content.

Together with capacity extension and modernising of equipment and technology suitability evaluation of wheat for starch production is under investigation again since several years. In particular the expanded use of centrifugal separation techniques suggested the utilisation of wheat varieties showing different grain characteristics. Effects of these developments on ongoing investigations have been reported previously with regard to flour preparation, laboratory scale evaluation of starch extraction and relevant small scale processes as well [21, 22]. Even though the various investigations did consider the practised new procedures they could not yet create a new criteria system for better suitable wheat varieties as grain or flour.

Derived from the fact that concentrated water/flour systems are more relevant in modern starch manufacture than dough systems and the importance of high mechanical energy input in gluten development prior to agglomeration two laboratory methods have been proposed as suitable in evaluation systems. These principles were regarded in both methods.

Table 5

Specifications for wheat grain and flour intended for starch production [22]

Grain Characteristics	
Minimum protein content [N.5,7](%)	12.0 to 12.5
Endosperm hardness	low
Falling number	medium to high
Amylograph consistency	medium to high

Table 6

Specifications used in wheat flour selection for starch production [22]

Flour Characteristics	
Maximum moisture content [%]	14.5
Maximum mineral content [%/% d.s.]	0.62/0.80
Minimum protein content [N·6.25]/% d.s.	12.0 to 12.5
Minimum falling number (s)	280
Minimum amylograph consistency (AU)	500
Damaged starch	low

In the gluten agglomeration test formation of the complex gluten structure follows water uptake and intensive extraction of soluble flour components including soluble proteins under the high mechanical strain of mixing the concentrated system. The applied active power is recorded time dependent. Derived estimates of the time necessary until significant power increase are used to characterise agglomeration.

In the mixer test the mechanical energy input is not only used in the concentrated but also in a diluted system comparable to decanting. This allows to evaluate the separability of the interesting flour components (i.e. A starch, B starch, gluten, and fibres) and in a further time-consuming procedure to determine their yield and purity.

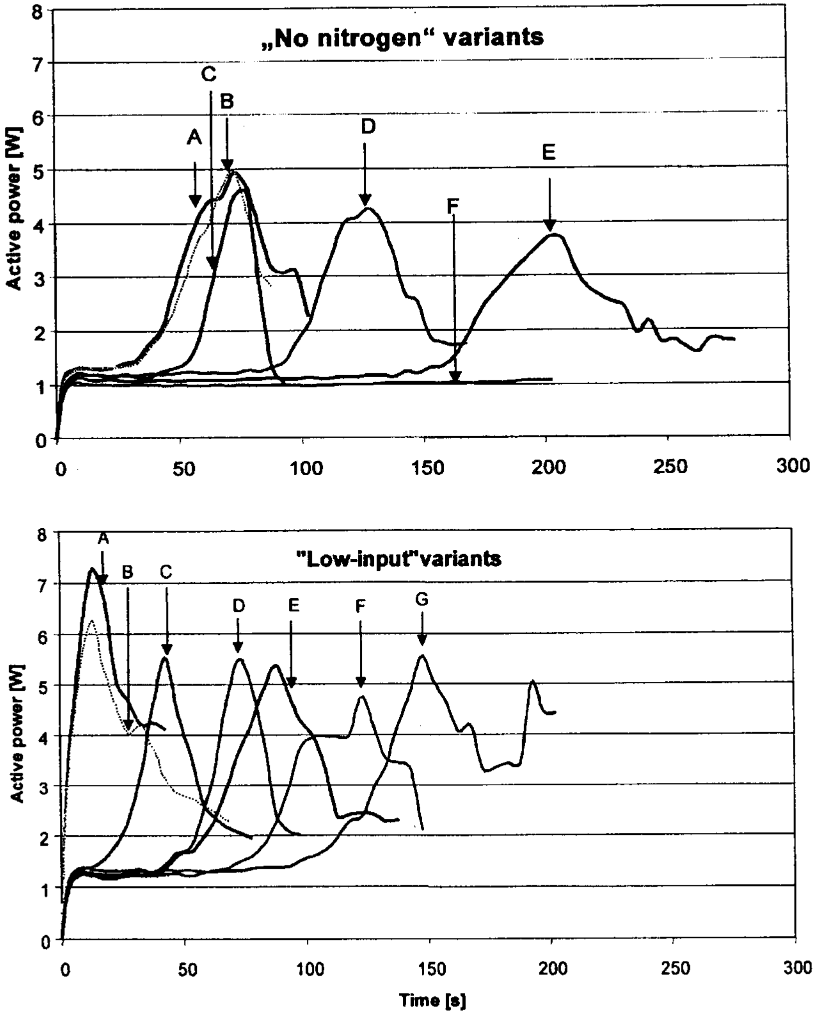


Fig. 6. Time-dependent formation of gluten of flour samples (cultivars: A = Residence, B = Ritmo, C = Atlantis, D = Contra, E = Contur, F = Crousty, G = Soissons) from nitrogen fertilisation trials in gluten agglomeration tests).

By applying these methods to divers sets of samples in particular such coming from fertilisation trials, it could be demonstrated that depending on the genetic potential of nitrogen acquisition of varieties grain produced under conditions of lacking or low-input nitrogen fertilisation will partially not allow satisfying processing [23]. Missing or inadequate gluten agglomeration becomes evident in long lasting or immeasurable agglomeration times (Fig. 6) or small gluten yields (Tab. 7). With some exceptions in all “no nitrogen” and “low-input” variants dry gluten yield was smaller than flour protein content. Calculated reductions laying in between 0.3 and 0.9% were expected as normal. Within the “no nitrogen” variants, for cv. Contur dry gluten yield was reduced by 1.6%. An explanation for the observed loss might be found in an increased protein content of the respective B starch fraction. A comparable, but less pronounced situation was given for cv. Crousty, too. Along the “low-input” variants differently oriented variations could be found with cvs. Residence, Crousty and Soissons. The small unexpected increases in dry gluten yield in case of cv. Residence and Crousty cannot be explained, yet. For the gluten yield loss with cv. Soissons the phenomenon seems to bee similar to the “no nitrogen” variant of Cv Contur. As result B starch yields and/or fibre yields rise exceptionally (figures in bold) while A starch yield is smaller than anticipated. These results are of particular relevance when grain produced exclusively under organic fertilisation (“extensive farming”) is intended for utilisation in starch production. Only varieties having high potential in nitrogen acquisition will thus be able to fulfil requirements.

Table 7

Yield characteristics of wheat varieties produced in a nitrogen fertilisation trial*.

Characteristics	Residence	Ritmo	Atlantis	Contra	Contur	Crousty	Soissons
"No nitrogen" variants							
Flour starch content (% d.b.)	83.7	83.7	83.3	82.5	83.0	83.0	---
Total starch yield (% d.b.)	82.1	83.9	83.6	83.5	85.2	**84.2**	---
A starch (%)	**71.9**	75.7	76.2	**73.1**	76.0	**72.5**	---
B starch (%)	**10.2**	8.2	7.4	**10.4**	9.3	**11.6**	---
Protein content (% d.b.)	2.6	2.5	3.2	2.9	**5.7**	4.6	---
Fibres yield (% d.b.)	1.1	1.1	1.3	1.3	**2.0**	1.3	---
Flour protein content (% d.b.)	9.1	8.4	9.2	8.7	8.5	8.5	---
Wet gluten (g)	23.6	20.0	22.8	21.8	17.5	21.7	---
Dry gluten yield (% d.b.)	8.6	7.6	8.5	8.1	**6.9**	7.6	---
"Low-input" variants							
Flour starch content (% d.b.)	7g,g	80.4	80.4	80.5	81.8	80.9	**80.4**
Total starch yield (% d.b.)	76.g	7g.2	80.5	82.3	82.2	80.7	81.0
A starch %	**66.6**	68.8	73.5	73.5	75.1	73.0	71.1
B starch (%)	**10.3**	10.4	7.1	8.8	7.1	7.7	9.9
Protein content (% d.b.)	2.3	2.2	2.5	3.3	**4.5**	3.1	**5.8**
Fibres yield (% d.b.)	0.9	1.2	1.1	1.3	1.3	**1.0**	2.0
Flour protein content (% d.b.)	13.3	11.7	12.3	10.6	10.9	10.9	11.9
Wet gluten (g)	39.5	31.6	32.3	29.2	29.8	**32.4**	28.9
Dry gluten yield (% d.b.)	**13.5**	11.0	11.8	10.3	10.3	**11.2**	10.6

*bold printed figures indicate divergences from expected levels

Developments in conventional breeding and genetic engineering

In contrast to maize extractability of starch was not defined being an interesting breeding task for wheat and played therefore never a important role in forming a new variety. Besides, in Europe wheat starch industry which was far of reaching processing capacities of maize starch production for a long time made in general use of baking flour quality available on the market. This situation was partly changed with the expansion of wheat markets in Asia and shifts in consumer demand to divergent suitability, for example for noodle and flat bread production. Following these demands and the fact that starch characteristics, in particular more waxy character, are connected with these applications, molecular strategies and plant breeding techniques were combined to alter expression levels of starch biosynthesis genes. By generation of mutant wheat lines with null alleles for GBSSI wheat lines could be formed with reduced amylose content or waxy wheat with more than 95% amylopectin [24]. Resulting starches showed higher peak viscosity and gelatinization temperatures, increased crystallinity and lower lipid content and thus a modified functionality in food products. Further presentations demonstrate availability of tools necessary for successful genetic modification of starch content, granule size distribution and shape, lipid content and different other aspects of starch functionality [24-26], but, with regard to the European Community the legal and the political situation as well are actually disadvantageous for their beneficial utilisation in modern biotechnology [27].

Recently presented preliminary results give an example that conventional breeding still may allow to affect the portion of small sized starch granules. Their quantity, in general, contributes significantly to the share of B starch separated in industrial processes. Crosses within *Triticum turgidum* and *Triticum aestivum* were basis of ongoing promising investigations [28].

Starch functionality and application

General considerations

Property profiles of starches are generated primarily by the botanical source and its genetic background [29]. It is well known that decisive contributions are coming from the ratio and structure of amylose and amylopectin. Applications in the food and non-food sector are, however, also determined by the morphology of starch granules (size distribution, form) and by the chemical composition of complex accompanying substances, as they are proteins, minerals, and lipids. With cereal starches serious technological relevance is ascribed to the lipid content (0.6–1.0%) since a certain part of lipids ("starch surface lipids") are hydrophobic surface compounds which affect starch characteristics decisively. As such they contribute to swelling and gelatinization properties, but also chemical reactivity and selectivity of reactions in granular state are expected to depend highly on the load of lipids [30, 31].

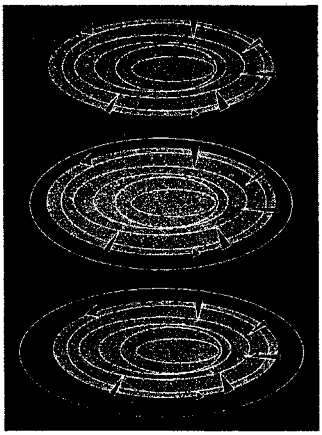
Empirical measurements performed under specific time and temperature procedures are in general successfully used to characterise standardised starch/water systems for application under practical conditions. Such measurements with wheat starches of different kind are well documented [12]. Since measuring conditions are often far from describing the real situation, these measurements provide just limited knowledge. More valuable information can be expected for example from rheometric measurements using well defined conditions of a horizontal cone/plate geometry in a relevant stress range [32].

Flow behaviour of starch suspensions

In starch technology the behaviour of aqueous suspensions plays an important role in process design. Description of the flow behaviour is a basic prerequisite in finding solutions for production processes. The multi-phase organisation of product systems impedes often an unmistakable characterisation of existing conditions. The typical temperature depending swelling behaviour of starch complicates such a description. It is well known, that the system starch/water forms suspensions of varied character in the temperature range from +5°C to 65°C. At higher temperatures (>65°C) the suspensions are transformed into pastes and then gels are formed by cooling. These transitions are influenced by a high number of different parameters which primarily affect packing within the given system [32].

With respect to aqueous suspensions of starch flow curves depend on characteristic parameters like concentration of dry substance, suspension density, suspension viscosity, sedimentation behaviour and stability. These parameters have to be considered in controlling measuring conditions. Nevertheless, such suspensions undergo steadily local and time dependent property changes which provide the flow curves a relative character. However, when measuring conditions are carefully adapted to practical conditions one can derive useful information even from measurements of quickly sedimenting suspensions.

Since surface compounds of starches are regarded as important for property profiles of starch/water systems starch products were used for measurement having very divergent surface properties as result of applied separation method. These products (commercial wheat starch; starch separated by a laboratory procedure: Glutomatic starch; starch recovered as insoluble fraction after Osborne fractionation: HMW starch) differed significantly in protein content (Fig. 7), but to a certain extent also in particle size distribution. In some way, they can be used to represent starches in different steps of industrial processing.



	Protein Content
Commercial Starch	0.3 %
Isolated Starch (Glutomatic)	0.8 -1 %
Starch Residue (Osborne) „HMWStarch“	4 -10 %

Fig. 7. Wheat starch products.

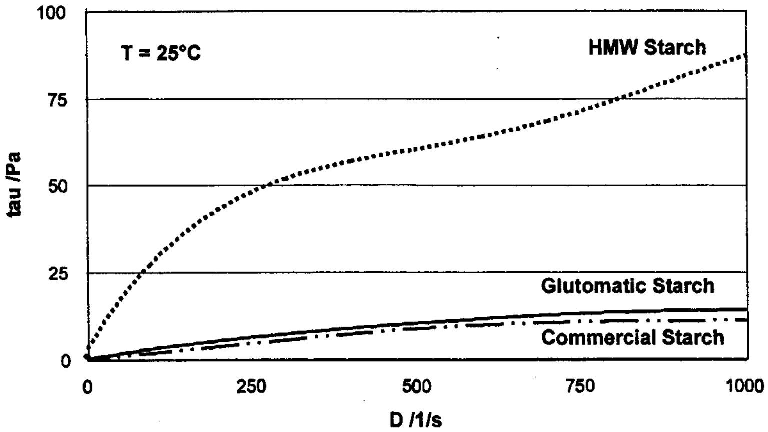


Fig. 8. Flow curves of different wheat starch preparations (T = 25°C).

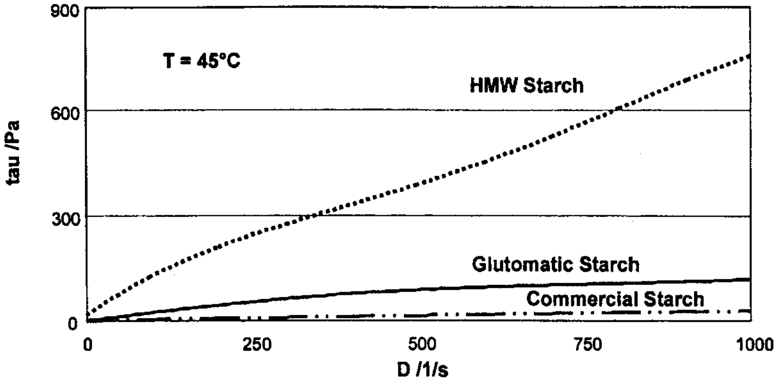


Fig. 9. Flow curves of different wheat starch preparations (T = 45°C).

Table 8

Specification of commercially available small-granule starches in comparison to the B-starch standard.

Quality characteristics	"HAMSTARCH ultrafine"	"Puramyl SP"	B-starch Standard
Colour	white	white	white/gray
Odour & taste	neutral	neutral	neutral
Moisture content (%)	10 - 13	15.0	max. 14
Starch content (% d.b.)	min. 97.0	-	-
Protein content (% d.v., Nx6.25)	0.3 - 0.6	max. 0.6	max. 5.81
Lipid content (% d.b.)	max. 0.1	-	max. 0.58
Mineral content (% d.b.)	max. 0.4	max. 0.6	max. 1.16
pH-value	5.5 - 6.5	5.3 - 6.7	-
Median particle size (µm)	3.4 - 4.2	-	-

Flow curves of aqueous suspensions of these starch products differed significantly when measured at T = 25°C (ambient room temperature) and T = 45°C (elevated temperature in processing, Fig. 9). At T = 25°C flow curves of commercial starch and Glutomatic starch were characterised by small but linear increases in slope while HMW starch demonstrated a higher, but not to drastic increase (Fig. 8). At 45°C the situation has changed. Now, even though the flow curve of the Glutomatic starch was separated from the one of commercial starch showing additional, even small contribution of structural changes within a dispersed phase of the suspension. The dispersed starch phase is considered of having changed its internal state of order. With regard to used scales a much greater contribution (nearly 10 times) to viscosity measurements, however, was observed with HMW starch. The temperature effects observed with the measured suspensions are expected to be different because of elucidated differences in type and amount of complex native accompanying substances. While in used commercial starch only lipoproteins and glycoproteins are present upon external layers and determine properties, amount and composition of HMW entities are decisive for the property profiles of Glutomatic starch, but to much greater extent for residues that remained on starch. This was in fact well reflected by the presented flow curves.

B Starch

A well known and until now unavoidable by-product of conventional processes in wheat starch production consists in an at most impure fraction of small sized (<10 µm) starch granules. Traditionally, this fraction is specified as B starch or, in Germany, also as "secunda" starch. Compared to regular A starch it contains much more impurities, e.g. proteins, lipids and minerals and resembles a product intermediate to Glutomatic starch and HMW starch. Because of utmost unknown functional properties, potential application of this starch type is limited. Therefore, B starch is either pre-gelatinised and used as animal feed or transformed into saccharification products. However, some European starch producers recover small starch granules and try to turn this fraction into a high quality marketable product. Removal of impurities, in particular pentosans, is done by enzyme treatments having pentosanase activity followed by usual regimes of starch refinement which may allow to admix the purified fraction to regular grade A starch. Commercial small-granule starch products do not reach fully specifications of A starch but offer remarkable quality (Tab. 8). They are marketed by several wheat starch producers (Latenstein Zetmeel B.V., Nijmegen/The Netherlands, brand name: "Puramyl SP"; Jäckering Mühlen- u. Nährmittelwerke GmbH, Hamm/ Germany, brand name: "HAMSTARCH ultrafine") [33].

Conclusions

Starch production was always affected by agricultural policy of the European Community which produced now conditions (export and production refunds, import duties) that favour utilisation of wheat. It's therefore not astonishing, that EU wheat starch and gluten production dominates world wide this market segment. Eastern Europe's production figures, including Russia do not even pass 6% of EU production. Political implications, in particular between US and EC authorities, impede market relationships in case of wheat gluten. Similar to market activities also technological developments progress much faster in Europe, presumably because of environmental reasons. Driving force is the need for restricted use of process water.

On the other hand new separation techniques based on centrifugal principles are replacing older principles and lead to introduction of new processes. Some prospects of success can be seen in introduction of pressure filtration as result of technical improvements. Focussing on products, there is concern for functional properties of gluten. Improvements in gluten drying regimes, yet less studied, are expected to allow better quality. However, since process economy and product quality are based on substrates more attention should be given to better adapted wheat and flour quality. For testing suitability new methods are in question regarding centrifugal energy application; a surveying gluten agglomeration test and the mixer method, that allows detailed information. Concerning utilisation of better adapted and potentially transformed wheat molecular biological techniques together with conventional breeding are expected to provide material with prospects in starch content as well as starch composition and morphology. The acceptance of genetically modified wheat remains critical as soon as wheat components are intended for use in food products. With respect to expanded application of wheat starch a lack of information is seen in selected fields of functionality. Empirical methods provide limited knowledge. The state of art in fundamental rheological characteristics needs to be expanded together with new and criti-

cal consideration of functional impurities. Flow curves can be valuable tools. Finally, a still problematic co-product, the B starch fraction, is waiting for new solutions.

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PSZENICA - KONKURENCYJNY SUBSTRAT W PRODUKCJI SKROBI

Streszczenie

W przeciwieństwie do sytuacji ogólnoświatowej, gdzie kukurydza stanowi główne źródło skrobi, w europejskim przemyśle skrobiowym pszenica zajmuje istotną pozycję. Chociaż wydajność techniczna tej skrobi nie może konkurować cenowo z innymi skrobiami, to gluten pszenny jest wartościowym produktem ubocznym pozwalającym skrobi pszennej zająć ważną pozycję. Nowe instalacje o dużej wydajności ostatnio zainstalowane w krajach europejskich są dowodem wzrostu zainteresowania tym surowcem. Jednakże sytuacja ekonomiczna produkcji skrobi pszennej ulega nieuniknionym wahaniom na rynku glutenu pszennego. Ważną rolę odgrywają też decyzje polityczne.

Konkurencyjna sytuacja, związana z pszenicą jako substratem skrobi, wynika z unowocześnień aparaturowych i zmian w technologii. Najważniejszą jest tutaj zmiana ilości wody na daną ilość mąki potrzebna do wydzielenia glutenu i skrobi oraz ich oczyszczenia. Osiągnięto postęp przede wszystkim przez unowocześnienie sposobu oddzielania skrobi w wirówkach. Z uwagi na brak wody oraz konieczne ograniczenie objętości ścieków ten problem wciąż znajduje się w centrum uwagi. Opublikowane standardy ograniczają się do wytycznych zorientowanych na proces Martina. Lecz z powodu unowocześnień proponuje się obecnie nowe metody standaryzacji. Wśród tych metod należy zauważyć metodę mikserową, postępowanie stosowane do mieszanek wody z mąką poddawanych wirowaniu. Jednakże jest to metoda czasochłonna, co ogranicza jej powszechne stosowanie. Omawiane są też techniki mielenia w połączeniu z wybranymi właściwościami ziarna.

W końcu omówiono postępy w konwencjonalnej hodowli i inżynierii genetycznej, pozwalające uzyskać substraty o większej przydatności do produkcji skrobi.