Patrick Navard *Editor*

The European Polysaccharide Network of Excellence (EPNOE)

Research Initiatives and Results

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Foreword

This is a book on polysaccharides. It is not the first book on this topic. However, this is not any book. Rather, it is unique in its scope and approach not only in dealing in an integrated way with different aspects—chemistry, biochemistry, interfacial phenomena, material aspects, etc.—but also in comparing different polysaccharides and discussing their applications. In recent years, we have in all sciences seen an increasing tendency to fragmentation of research. Specialisation is of course a necessity in research, but a neglect of using information "around the corner" counteracts deep-going research and leads to duplication of research. We can certainly see this in research in the fields of macromolecules, with a specialisation not only on one type of macromolecules—synthetic, polypeptides, polysaccharides, polynucleotides, etc.—but even more so, for example, a group specialising on one protein or one polysaccharide, making little attention to the fact that mechanisms and interactions may have been clarified for a very similar system. In the scientific world of polysaccharides, this has been exemplified for polyglucoses, with groups working on cellulose and starch, for example, having little exchange of ideas or information. It is interesting to note that the European Polysaccharide Network of Excellence, with the acronym EPNOE, well known in a wide part of the scientific world, was created with a broad scientific scope.

Behind the ability to prepare a qualified treatise of a scientific topic, like this book, there must of course be a corresponding research effort, which is outside the capability of a normal research group. It requires instead a larger constellation of researchers, who are able to work together and interact constructively. EPNOE is such a research venture. It started from scratch on the initiative of Patrick Navard and a few insightful individuals with great visions. The opportunity of creating EPNOE was certainly dependent on the support from the European Commission. However, unlike many such analogous consortia which tend to dissociate into the individual starting groups as soon as the funding finishes, EPNOE built up a strength due to strong research to not only survive but also develop and expand with time. I would say that EPNOE in important respects is unique and should serve as an excellent example for future attempts to create strong collaborative research organisations. The important role played by EPNOE has been recognised by a large number of companies which have joined the organisation. This, in addition to its enormous impact on academic research, will make EPNOE a lasting venture as a centre of the international research on polysaccharides.

During more than 5 years, I have been able to follow EPNOE, first during 2 years as the European Commission appointed evaluator of the Network of Excellence and thereafter in several collaborative projects and as a participant in several conferences and workshops organised by the EPNOE community. Prior to the invitation to act as an evaluator, I had essentially no contacts with the EPNOE partners. As an evaluator, I was struck by one particular aspect in our evaluation meetings: this was the great interest in receiving critical comments to the various activities, even asking for additional critical comments and attempts to identify weak aspects of the consortium. Any such comment was seriously considered and commented on, frequently leading to follow-up questions.

Whereas an important aspect of the creation of EPNOE was the ability to identify an area of research of deep academic and fundamental interest as well as being highly industrially relevant, the critical point was certainly to bring leading research groups together and make them work truly together. This requires a strong and committed leadership. The demanding and sensitive task of bringing strong scientists together and working in the same direction is not easy to achieve, but Patrick Navard’s and his colleagues’ efforts in this respect have been spectacular. The introductory chapter of the book gives an interesting account of the “EPNOE saga”, describing also the significant non-scientific obstacles in building a multinational network and the subsequent introduction of industrial companies as members.

For myself, the increasingly tighter contacts with EPNOE itself as well as with several partner groups individually have been most rewarding. Whereas I was involved rather extensively in polysaccharide research in the past, the contacts with EPNOE have taken my research into completely new directions. Thereby, I have benefited very much from the open atmosphere in EPNOE and the willingness to discuss controversial issues.

It was with enormous interest I received the manuscripts of this book. The breadth covered, from molecular and chemical characterisation, via manipulation and modification to various industrial aspects will make this book an important reading for students in several disciplines, as well as researchers in both academia and industry. The polysaccharide community is to be congratulated! This book marks a further step in the already extremely strong dissemination programme of EPNOE, including regular publications, courses, workshops and the biannual EPNOE polysaccharide conference. This conference was organised in Finland in 2009 and the Netherlands in 2011 and will be in France in 2013. EPNOE conferences are already an institution which is gathering all important scientists in the field.

Lund University and Coimbra University
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Sweden
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Björn Lindman

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1 Introduction: Challenges and Opportunities in Building a Multinational, Interdisciplinary Research and Education Network on Polysaccharides

Julie Navard and Patrick Navard

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1.1 Need for Organising Research and Education in the Polysaccharide Field

Polysaccharides represent by far the largest group of polymers produced in the world. Fully biodegradable, they are made by nature. They are the major source of carbon, on which our life and activities are based. Carbohydrates are the result of photosynthetic CO_2 fixation in plants and the central exchange and communication system between organisms. Polymeric carbohydrates (or polysaccharides) such as cellulose and chitin are natural polymers found abundantly in nature as structural building blocks. Other polysaccharides (starch, inulin) provide stored solar energy in the form of sugar for fuelling cells. Oil, gas and coal, made of (very) slowly modified biomass, have been cleverly used by humans to be a major energy source as well as a source of materials. Several factors are pushing for the use of the renewable biomass, i.e. the one that can be harvested in fields and forests. The first is the fact that 1 day or another, oil, gas and coal will be exhausted. Even before this time, the costs of exploitation will be higher and higher due to the fact that all easy-to-extract fossil biomass have been collected. The second is the push for preventing to send in the atmosphere the carbon present in fossil resources. A third driver for the use of renewable biomass is the more and more acute awareness of citizens about environmental issues that is influencing marketing departments of companies.

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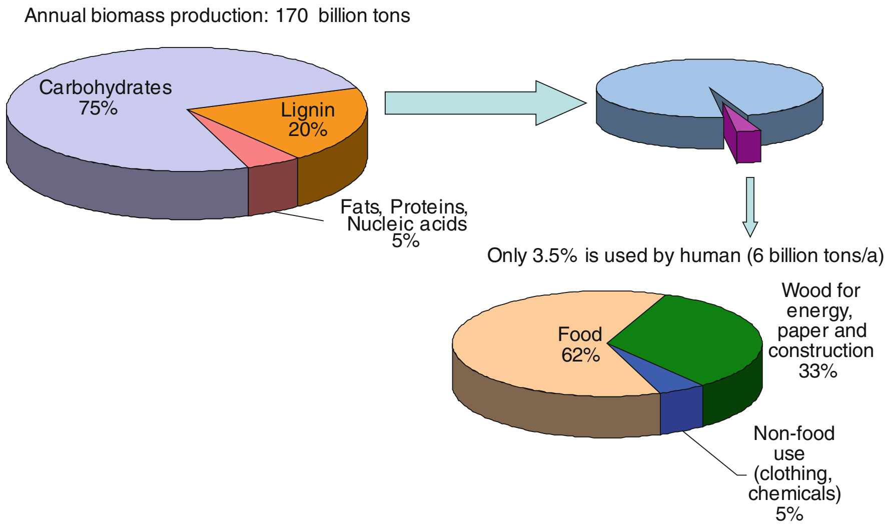


Fig. 1.1 Annual biomass production and use by humans (adapted by EPNOE partners Li Shen and Patel, Utrecht University from Thoen and Busch 2006)

Human beings are using a small portion of the whole biomass production (Fig. 1.1).

Biomass is mainly polysaccharides or molecules closely associated with them like lignin and proteins. All the new biorefinery concepts under development around the world and all the future trends in agriculture are linked, one way or another, to polysaccharides. From all sides, polysaccharides will be at the centre of a new emerging era in which sugar will be the value unit due to the emergence of a bioeconomy that will increase the contribution of bio-based products.

Polysaccharides are used in all sectors of human activities like materials science, nutrition, health care and energy. They are polymers with exceptional properties, far from being fully recognised, able to open routes for completely novel applications. In the global bioeconomy, carbohydrates, e.g. sugars and polysaccharides, are the central source of energy within which an economic value is intrinsically entrapped.

However, all the products present in nature are mixed with many other components in order to perform their biological role. Extraction, purification and treatment of these products are critical issues that have not been solved in a satisfactory way in most practical cases, leading to either polluting or energy-intensive treatments. But on the other hand, a widely unused source of polysaccharides is dormant in the waste of municipal water treatment, agricultural and food industries, leaving here huge potential sources of matter without conflicting with the food chain. The number of projects dedicated to and the amount of money poured in the development of polysaccharide-based products and fuel are the signs that a new industrial revolution might be emerging. Polysaccharides and polysaccharide-based polymers offer credible answers to the challenges faced by the world in terms of global sustainability.

For many reasons, including the fact that their structure is variable (depending on genetics, climate, location on Earth, soil, etc.), their use in highly engineered functional materials is in its infancy. Nevertheless, and withstanding all difficulties, polysaccharides are the sustainable source of polymeric materials for tomorrow. They offer numerous product development opportunities that are increasingly attractive in light of tightening oil supplies and rising concerns over environmental and biodegradability issues. The use of renewable raw materials such as polysaccharides is one of the targets of the European Union policies with objectives to increase the share of renewable energy and to promote biodegradation. Fixed targets of the

European Council of 8–9 March 2007 are the following: by 2020, at least 20 % reduction in greenhouse gas emissions compared to 1990 (30 % if international conditions are right, European Council, 10–11 December 2009); saving of 20 % of EU energy consumption compared to projections for 2020; and 20 % share of renewable energies in EU energy consumption, 10 % share in transport. On 15 December 2011, the European Commission adopted the Communication "Energy Roadmap 2050" (European Union 2011) that committed EU to reducing greenhouse gas emissions to 80–95 % below 1990 levels by 2050 in the context of necessary reductions by developed countries as a group.

In the same trend, one of the six EU Lead Market Initiatives targets bio-based products defined by the Ad-hoc Advisory Group for the Lead Market Initiative as products made from biological raw materials such as plants and trees that are renewable raw materials. It excludes food, traditional paper and wood products but also biomass as an energy source. Bio-based products can substitute fossil-based products. They are neutral in terms of greenhouse gas and leave a smaller ecological footprint, i.e. generate less waste and use less energy and water. Less consumption of natural resources lowers production cost and is better for the environment. This definition is totally fitting polysaccharide-based products.

These are the main reasons why the European Commission selected the polysaccharide topic for supporting the building of the European Polysaccharide Network of Excellence, better known as EPNOE.

1.2 Building the EPNOE Network

In 1999–2001, there was a dense informal network around cellulose with EU academia and industry. In 2002, the European Commission launched a manifestation of interest for creating networks in Europe. Several academic and industrial partners built a first consortium and submitted a network on cellulose called Cellnet. Considered too narrow by the European Commission, it was extended to polysaccharides. In 2003, the "*Polysaccharides*" proposal is submitted as a Network of Excellence. A Network of Excellence was a novel type of virtual research organisation at the level of the 25 countries of the European Union that was implemented by the European Commission. According to its definition, its purpose was to strengthen excellence on a particular research topic by networking together the critical mass of resources and expertise needed to be world force in that topic. A Network of Excellence was an instrument designed primarily to address the fragmentation of European research on a particular research topic, for which the main deliverable would be a restructuring and reshaping of the way research is carried out on that topic. It was thought to be the foundation stone for the construction of the European Research Area.

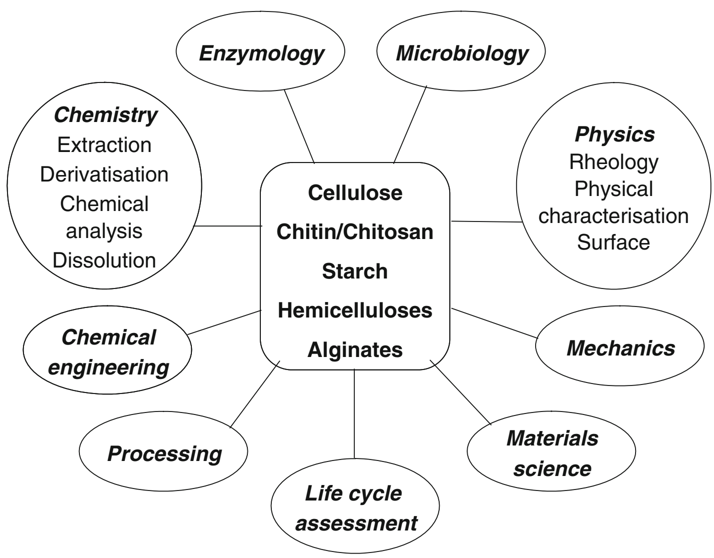
"Polysaccharides", very quickly called EPNOE for European Polysaccharide Network of Excellence, was very well ranked (first step: first over about 200 proposals at the first step and second over the remaining 36 proposals at the final stage) and was accepted. EPNOE started in May 2005 for 4 years and a half. EPNOE associated 16 European laboratories from 9 countries (Fig. 1.2).

The 16 institutions are composed of top-ranked universities and research centres, which have developed scientific expertise and state-of-the-art technologies in polysaccharide-related disciplines including chemistry, enzymology, biotechnology, chemical engineering, mechanics, materials science, microbiology, physics and life cycle assessment (Fig. 1.3). The following is the list of members (note that there is no number 14):

1. Centre de Mise en Forme des Matériaux CEMEF, ARMINES-Ecole des Mines de Paris/CNRS, France
2. Department of Chemistry, Universität für Bodenkultur, Austria
3. Centre of Excellence for Polysaccharide Research at the University of Jena, Germany
4. Fraunhofer-Institut für Angewandte Polymerforschung, Germany
5. VTT Technical Research Centre, Finland
6. Johann Heinrich von Thünen-Institute, Germany

Fig. 1.2 Location of the 16 academic/research partners

Fig. 1.3 Expertise within EPNOE



7. Process Chemistry Group, Laboratory of Forest Products Chemistry, Abo Akademi University, Finland
8. "Petru Poni" Institute of Macromolecular Chemistry, Romania
9. Laboratory for Characterization and Processing of Polymers, Faculty of Mechanical Engineering, University of Maribor-Univerza v Mariboru, Slovenia
10. DLO-FBR Stichting Dienst Landbouwkundig Onderzoek, Wageningen University and Research, The Netherlands
11. Thüringische Institut für Textil- und Kunststoff-Forschung (TITK), Germany
12. Institute of Biopolymers and Chemical Fibres – Instytut Biopolimerów i Włókien Chemicznych (IWCh), Poland
13. School of Biosciences, Division of Food Sciences, University of Nottingham, UK
14. Institute of Textile Chemistry and Textile Physics, Christian Doppler Laboratory for Textile and Fiber Chemistry, Universität Innsbruck, Austria
15. Department of Science, Technology and Society (STS), Universiteit Utrecht, The Netherlands
16. Institute of Chemistry, Colloid & Rheology Group, Universität Graz, Austria.

The main mission of EPNOE was to promote the use of polysaccharide renewable raw materials as industry feedstock for the development of advanced multifunctional materials.

The objectives were the following:

- To stimulate exchange and collaboration between the members through training and technology transfer activities
- To spread knowledge and excellence in the European Union scientific, industrial and public communities
- To develop a world-class research network.

From its initial structure, EPNOE evolved from an informal network composed of 16 academic/research institutions to a new formal structure. In 2007, the EPNOE network became a non-profit organisation called EPNOE Association. EPNOE Association is the current independent structure organising all the EPNOE activities. It is only funded by membership fees. Members are the initial 16 academic/research institutions plus companies. At the beginning of 2012, 25 SMEs and multinational companies working in various application fields such as food, paper, engineering and health are EPNOE members.

EPNOE is now a durable structure for organising Research and Education on polysaccharides at the European level. It is a complete, efficient and innovative research network on polysaccharide worldwide and a platform for bringing together companies and research centres.

1.3 Organisation of EPNOE

Although the main aspects of integration were clear at the beginning of the EC project, it took 2 years and a half to design and register the EPNOE Association. The EPNOE Association is a non-profit organisation under the French law "association loi 1901", registered in Paris on 14 December 2007. Its members are legal entities, physically represented in the various boards by persons they nominate. From the original concept to the design of the structure, many obstacles had to be overcome, the most complicated one being to find a structure in which the institutions would feel legally safe, considering that some of the partners not established in France would have positions implying responsibility like president or vice-president. At the present time, EPNOE is lead by the president, Dr Pierre Avenas (ARMINES, France), the vice-president for research, Prof. Karin Stana Kleinschek (University of Maribor, Slovenia) and the vice-president for education, Prof. Pedro Fardim (Abo Akademi, Finland). The absolute objective was to keep all partners on board, overcoming all administrative, legal or internal policy difficulties.

EPNOE Association has two types of members, regular members (academic/research institutions) and associate members (companies). It is organised with two legal documents (registered statute and association rules). Three boards are in charge of running EPNOE: a general assembly in which all regular and associate members vote for the plan of activity and approve budgets every year; a governing board, comprising one representative per regular member, that takes care

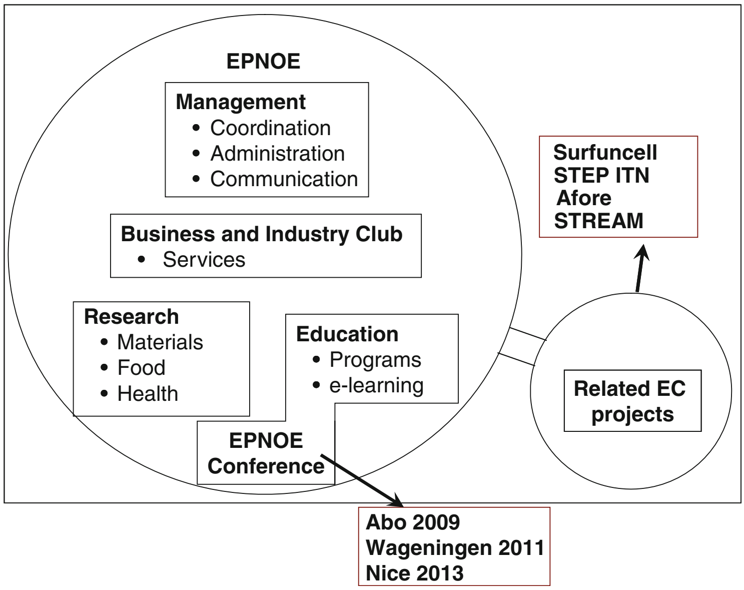


Fig. 1.4 Structure of EPNOE and EPNOE-related bodies

twice a year of the many decisions needed to fulfil the plan of activities; and the executive board, meeting about every 2 months (can be more often), that takes the operational decisions, implemented by the president and its representative.

The overall structure is given in Fig. 1.4. It shows the activities of EPNOE and of some EPNOE-related activities. Companies are mainly involved in the Business and Industry Club which was created to build a solid bridge between the 16 EPNOE academic/research members and industrial members. It is tailored to gain fast transfer and exploitation of knowledge, ideas and new processes and to offer its members a multidisciplinary and collaborative R&D platform. The Business and Industry Club offers four services:

1. Access to EPNOE Partner Databases: The objectives are to offer an easy access to and to give a complete general picture of all the 16 academic/research partners. The list and description of each partner, the list of all on-going PhD and master's theses, a list of CVs of master and PhD students looking for employment and the name and details of all EPNOE researchers with their field of expertise are regularly updated.
2. EPNOE Research Information: In order to facilitate knowledge transfer, the maximum research information that is possible to be made available to other partners considering confidentiality issues and regulations is placed on the site like the full text of non-confidential EPNOE partners' PhD and master's theses, reports on the common basic and non-confidential research undertaken by EPNOE members.
3. Strategic and Technological Watch Data of EPNOE: The objectives are to offer information regarding the various stakeholders dealing with polysaccharides. An innovative and useful tool is the access to information on national-language conference papers. The title and details of communications dealing with polysaccharides of more than 150 conferences in 13 non-English languages are available. Several EPNOE market studies are also available.
4. Organisation of Dedicated Meetings.

EPNOE has been successful due to the strong links created during all these years of collaboration among the 16 partners. All partners are formally meeting at least three times per year all together and many times more in other meetings to discuss management, science and/or education. It is estimated that eight to ten meetings with the presence of all or part of EPNOE members are taking place every year since 2005.

EPNOE is now a well-known network, respected all over the world due to the highest quality of the research performed by its members, to its involvement in the international scientific life and to the development of its communication tools like the EPNOE Newsletter (20 issues published since November 2006 and distributed to now more than 400 subscribers). A look at Google shows that EPNOE is cited more than 8,000 times (65 times in Japan, 60 times in Brazil, 380 times in China, 1,800 in USA, etc.), the highest or one of the highest scores among all networks of excellence. Its contact address (contact@epnoe.eu) is attracting on average ten requests per week.

1.4 Facts and Figures: The Achievements of EPNOE

The main achievements of EPNOE members are the following:

- Establishment of a legal structure called "EPNOE Association" able to ensure a durable networking over the next 5–10 years.
- Creation of an active network involving 16 institutions, more than 20 companies, 100 scientists and more than 70 PhD students.
- Building of a research and education road map 2010–2020.
- Top-level scientific research (more than 40 on-going common research projects, about 20 PhD shared by two partners, round-robin testing, tool box with a set of 200 instruments available within the network).
- Education, with more than 50 exchanges of students, and creation of one EC-Intensive Programme on "Sustainable Utilization of Renewable Resources" (2009–2011).
- Active industrial membership with 25 members.
- Every year, more than 270 research projects are starting between EPNOE members and companies.
- High-level participants in many important stakeholder organisations (like organisation of meetings with scientific societies).

Some of these achievements are detailed below.

EPNOE Research Road Map: Partners prepared in 2009 a new joint EPNOE Road Map on polysaccharide research and development needs for the next decade (2010–2020), with a broad scope, encompassing materials, food and health. The research road map was prepared considering various social, political, industrial and scientific inputs (like market studies, EC documents and European Technology Platform strategic agendas), as well as other inputs from inside and outside EPNOE, mainly (1) results of four brainstorming sessions by EPNOE scientists and students, (2) individual contributions of EPNOE scientists and (3) individual contributions of scientists outside EPNOE through an internet review. The EPNOE Road Map has a research section structured around two main focus areas as shown in Fig. 1.5. The first, called "Fundamental basis of polysaccharide science", is where scientific challenges common to all application fields associated with major socio-economic and technological factors are reviewed. The second deals with the three selected "Application fields": materials, food and health care. For each application field, three levels of product cycle are considered: (1) extraction (disassembly), (2) conversion (reassembly) and (3) consumption (end of life cycle). In addition, the materials field has a section on economical and environmental assessments.

The EPNOE Road Map 2010–2020 has two versions: an extended one only available to EPNOE members on the internal website and a short public version only focusing on research (EPNOE Research Road Map 2010–2020). In order to disseminate this work, an article-like version of the short EPNOE Research Road Map was published in January 2011 in a major journal of the fields *Carbohydrate Polymers:* Z. Persin, K. Stana-Kleinschek, T. Foster, J. van Dam, C. Boeriu and P. Navard "Challenges and opportunities in polysaccharides research and technology: The EPNOE views for the next

Fundamental basis of polysaccharide science

Application fields

	materials	food	health care
dis-assembly	biorefinery tools	isolation/extraction	extraction/purification characterisation
re-assembly	product manufacturing	texturation and structure creation	biocompatible, functionalized products
end of life cycle	recycling/composting biodegradation	digestion/nutrition	depends on function

Fig. 1.5 Content of the EPNOE Research Road Map

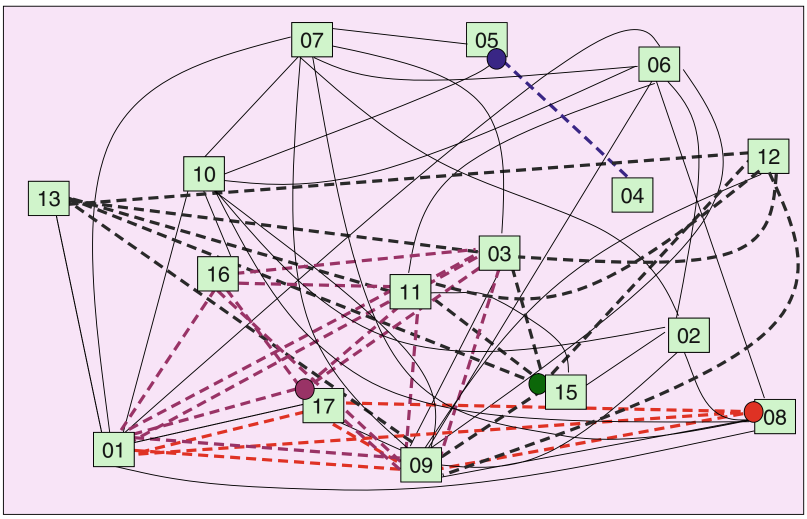


Fig. 1.6 Bilateral collaborations between the 16 academic/research laboratories (identified by numbers referring to the list given in the text) in 2011. The *four dots* are located on partner's institutions coordinating EC projects related to EPNOE

decade in the areas of materials, food and health", *Carbohydrate Polym*, vol 84 (2011) pp 22–32.

Applied R&D Research: R&D activities with industry have been increasing enormously within partner's institutions in large part, thanks to EPNOE. In 2007, 170 industrial projects were running, amounting to 13M€. In 2009, 270 industrial projects were running, amounting to 26M€.

Four running EC projects originate from the EPNOE activities: Surfuncell, STEP, Afore and STREAM.

Collaborative Research Activities and PhD/Postdoc Mobility: Collaborative research activities are very active among partners. At the beginning of EPNOE, only a few formal collaborations existed. In 2011, 62 such collaborations were active (Fig. 1.6) in various forms (EC projects, binational projects, visits of PhD students or postdoctoral scientists, basic science research, industrial projects).

Courses and e-Learning: Regular courses and meetings dedicated to industrial scientists or to postgraduate students have been or will be organised (last ones in May 2010 in Wageningen, The Netherlands, September 2010 in Sophia Antipolis, France, March 2011 in Lodz, Poland, August 2011 in Wageningen, September 2012 in Erfurt, Germany, September 2013 in Nice, France), and a set of tutorials on polysaccharides are posted in the EPNOE Web site (http://www.epnoe.eu).

Dissemination: scientists are very active in publishing their work and participating in conferences. More than 400 papers were published under the name of EPNOE, among which more than 50 papers were co-signed by at least two different EPNOE members. More than 400 communications at conferences were given with EPNOE name. EPNOE members organised or co-organised more than 40 conferences in Europe, China, India and USA (including a formal EPNOE—American Chemical Society collaboration), such as:

- *EPNOE—American Chemical Society session with cooperation of the US Department of Energy* (New Orleans, USA—April 6–10, 2008. ACS National Meeting)
- *EPNOE—Polymer Processing Society polysaccharide meeting*, Goa, India, 1 March 2009
- *1st international conference on Bamboo Fibre*, Quanzhou, China 23–25 March 2009
- *Polysaccharides as a sources of advanced materials*, EPNOE Conference, Abo, Finland, 21–24 September 2009
- *Narotech*, Erfurt (Germany), 9–10 September 2010
- *11th European Workshop on Lignocellulosics and Pulp*, Hamburg (Germany), 16–19 August 2010
- Series of *ACS meetings* every year

EPNOE Education Road Map: The targeted users of EPNOE education are students and postdocs, academic staff, industrial scientists, researchers and the general population. The aim of EPNOE education is to meet these demands with the help of education actions, which are divided into three action points: academic education, courses and e-learning and dissemination. EPNOE formally participated in education activities at the European level such as the EC-Intensive Programme on “Sustainable Utilization of Renewable Resources” (2009–2011).

EPNOE Tool Box: An infrastructure called “tool box” was developed by EPNOE in order to offer its members the possibility to figure out which member has instruments able to measure or estimate a given set of parameters. This database is associated to dedicated software enabling to search with different entries like the type of polysaccharides, the type of measures or the type of instruments. So far, more than 280 instruments are in the tool box database, with its major last update done in January 2011. This database is associated with a general agreement among members, part of the Association Rules of EPNOE Association that specifies the conditions of use of a piece of equipment from another member’s institution. So far, there was in all cases a free access to equipment of other laboratories without any reported difficulty.

Joint Communication and Involvement in the Scientific, Policy and Industrial Communities: The EPNOE Newsletter is regularly published (20 issues so far) and has more and more subscribers (more than 450 now).

EPNOE scientists are (1) active participants in many important stakeholders’ organisations like Technology Platforms (Suschem, Forestry, Food for Life), national organisations (pole de compétitivité in France, Polymer Institute in the Netherlands, Christian Doppler Laboratories in Austria, Zellcheming in Germany, etc.) and European organisations (European Renewable Raw Material Association, Advisory Group of the European Commission’s Lead Market Initiative (LMI) on bio-based products); (2) board members of many organisations, that is, “Austrian Association of Textile Chemists and Colorists”, “Electrokinetic Phenomena”, “European Bioplastics”, “Electrokinetic Society”, “Forschungsvereinigung Werkstoffe aus nachwachsenden Rohstoffen”, “Kunststoffnetzwerk

Brandenburg", etc.; and (3) members of editorial boards of journals "Cellulose", "Cellulose Chemistry and Technology", "Carbohydrate Polymers" and "Natural Fibers", "Holzforschung", "Arkivoc", "Current Organic synthesis", "Letters in Organic Synthesis", etc.

1.5 Challenges Around Networking and Opportunities Brought by EPNOE

To build a network, i.e. to construct links between the members of a group of institutions or persons, is most of the time thought to be the best way to increase efficiency. In most countries, networking different research institutions is compulsory for submitting projects to funding agencies. It is usually taken as granted that a network is much more efficient than the sum of its components. Although it can be true, and EPNOE is one example, we believe it may not be the case in many instances, especially when networking is compulsory. The advantages of a network are clear. Since no single researcher or no single research group can usually master the whole chain of expertise to treat a scientific problem, especially when several disciplines are at stake, there is no other choice than to bring together different research groups to solve a question. Often, when a research group is alone and obliged to use techniques, theories or modelling that are a bit far from its own scientific experience, errors and misinterpretations are numerous. All reviewers of submitted papers have experienced this very common effect. In this case, the search of a complementary competence outside the leading group is needed. This is exactly the driving force that hides behind the 62 collaborations shown in Fig. 1.6. In most of the cases (not all), these collaborations proceeded from the need to find a complementary expertise. In these cases, the existence of a network is very important: research groups know precisely what the others can do, under which time and under which resource conditions. But to reach such a state is a complicated task. Putting aside financial aspects, to build a research network with research groups that are competing for fame, are competing for money and are usually knocking at the same doors for funding, is complicated. Each member must feel that it will gain something from being a member of this network. In addition, it must also be sure that decisions are taken is a totally transparent and fair process. What we call an "*area of trustiness*" must be established. Contrary to what is usually thought and planned, this takes a lot of time. In the case of EPNOE, it took probably 5 years to start having research scientists willing to give some ideas without the risk of having them stolen by another member. Time, fairness and gain for members are the first ingredients for building a stable, long-lasting network. If these characteristics are not met, networks can exist, but they will be based on immediate opportunism, usually to solve one specific question or most often because networking is a request. *Opportunism networks* are short-life structures. In many European Commission consortia, some partners do not participate because they are the best to solve the scientific or technological challenge but because of requests like having SMEs as industrial members or researchers from certain countries.

Another difficulty with networks lies in the fact that the larger it is, the more time is lost to run it. It is like parallel computing where the speed of calculation is not the sum of the performances of the individual computers but lower due to the need for computers to exchange information. Exactly the same applies to research networks. It takes a lot of energy for individual members to perform activities dedicated to the network administration and to know the other groups. This loss of energy must be much lower than the gain of energy linked to the benefits of being a member. E-mails are a dramatic factor able to incredibly increase the loss of energy if too many are sent to too many people. Therefore, they must be limited to the minimum, despite all members must be aware of the running of the network. The same applies to meetings that must have a very rigorous format to be efficient in terms of energy lost. EPNOE meetings are structured in a very specific way. Each meeting has a "preparation document" that details all the points to be addressed and all the decisions that have to be taken point by point. The format of this "preparation document" is the precursor of the "minutes" of the meeting, with the same exact format. Below each point is the decision that is completed on line at the end of the discussion and vote. Except for phone meetings, the decision is shown on the screen. At the end of the meeting, minutes are nearly completed, and they can be sent for approval within days and posted, when approved, on the Web site. All "preparation documents" and thus all "minutes" have the same format, year after year. They contain all information pertaining to the meeting.

Network management must be optimised with very specific management tools far from the ones taught in management schools and with an effective *chain of command*, able to ensure minimum communication energy dissipation, maximum information flow and total transparency of decision and governance. EPNOE experienced many difficulties at its beginning and invented its own efficient management strategy. This participated to the fact that all the members that have built EPNOE over its first years are still present and active. This created a strong "*network*" that is recognised worldwide as an efficient and productive structure, able, for example, to build a long-lasting collaboration with the largest scientific society in the world. The fact that hundreds of research groups asked to join EPNOE is the sign of its success. As can be easily understood, above a certain size, the dissipation of energy to run a network is higher that its gain, and there is no more interest in networking. For EPNOE, the limit is close to the present number of 16 academic/research members, and so far, no other research institution was allowed to join for this reason, despite their clear scientific merits for most of them.

Conclusions

EPNOE is a success due to the commitment of its academic/research members, the initial support of the European Commission and the continuous support of its industrial members. This network has managed to be very active and fruitful owing to its clear, easy-to-manage and transparent organisation. All partners are benefiting, one way or another, from EPNOE. Without such benefits for the institutions and more important for the individual members, EPNOE would not exist.

A new EC-funded project, called EPNOE CSA, started in March 2012 for a duration of 3 years. EPNOE CSA (CSA stands for Coordination and Support Action) is composed of the same 16 academic/research members of EPNOE. It aims at ensuring a durable financial viability to EPNOE Association while strengthening academia/research and industry relationship and promoting knowledge transfer with three objectives:

- Expanding EPNOE activities towards health-related materials and products
- Expanding EPNOE activities towards food-related materials and products
- Increasing financial viability via industrial participation and innovation by (1) installing the tools for increasing the financial viability of EPNOE during the 3 years of the EPNOE CSA project in order to ensure long-term sustainability of EPNOE Association activities after the project and (2) improving partnership with industry and boost innovation and knowledge transfer

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Etymology of Main Polysaccharide Names

2

Pierre Avenas

Contents

Abstract

This chapter deals with the etymology and history of names of the main polysaccharides and of some of their constitutive saccharides. The considered languages are mainly those which are used by the 16 academic EPNOE members, which are also the founders of EPNOE Association. Most of these nine languages belong to the Indo-European family (which includes also Greek and Latin), and they are distributed among the Germanic group (English, German, Dutch, Swedish), the Roman group (French, Romanian), and the Slavic group (Polish, Slovenian). Among the nine languages, the only non-Indo-European one is Finnish, which belongs to the Finno-Ugrian family.

2.1 Introduction: Etymology

Etymology studies the origin and history of words. The interest of this approach lies in the fact that the etymology (from Greek *etumos* "true") of a given word generally tells something about the reality which lies under this word. The present chapter deals with the etymology of the names given to the main saccharides and polysaccharides consumed and used by people.

For instance, the common name of a chemical substance is often related to the name of a plant from which the substance has been first isolated. That is true for saccharides like *sorbose* or

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rhamnose. The name of a substance can also be related to a specific part of plants, like cell wall for *cellulose* or fruit for *fructose*. In other cases, it can be related to an animal component, like liver for *heparin*, insect carapace for *chitin*, and milk for *lactose* and *galactose*. However, the link between the substance and its name can be quite different when it involves a particular property, like sweetening for *glucose*, stiffening for *starch*, and thickening for *pectin*. In any case, the common names of polysaccharides as chemicals are officially retained by IUPAC organization. Besides the names of some important mono or disaccharides, the complete list of which is huge, the following chapter will insist more on the well-known polysaccharides: **cellulose**, **starch**, **chitin**, **carrageenan**, **inulin**, **pectin**, **heparin**, and **pullulan**.

Let's begin this exploration with the name *polysaccharide* itself.

2.2 *Saccharide* and *Sugar*: One Origin for Two Synonyms

A polysaccharide is a polymer (from Greek *polu* "many" and *meros* "part"). A monomer is made of only one part, a dimer of two parts, and a polymer of many parts. Polysaccharides are sometimes called *polymerized sugars*. In other words, *saccharide* and *sugar* are roughly synonyms: the former being a scientific term, while the latter is also used in chemistry (for instance, in the phrase *sugar unit*) but mainly in common language, for ordinary *table sugar* in tea or coffee.

- The word (or element) *saccharide* is made of *sacchar*-, which means "sugar," and the suffix -*ide* (from Greek *eidos* "species"), which indicates the belonging to a family: a saccharide is a molecule of the family of sugars. It is the same name as English in German and French and nearly the same in Dutch (*sacharide*), Swedish (*sackarid*), Finnish (*sakkaridi*), Polish (*sacharyd*), Slovenian (*saharid*) and Romanian (*zaharid*).
- Both *saccharide* and *sugar* are derived from Sanskrit *çarkarā*- "gravel," and later "sugar" (originally, granulated sugar):
  - *Saccharide* was recently derived, in scientific language, from the Latin word *saccharum*, continuing Greek *sakkharon*, which was the name of a product imported from India during antiquity. As a matter of fact, this product was something like cane sugar used only in small quantities and mainly for medicinal uses. At that time in Europe, the general way of sweetening food and beverages was with honey.
  - *Sugar* was derived, through Old French, from Arabic *sukkar*, when the cultivation of sugar cane was introduced in southern Europe by the Arabian agronomists around the Middle Ages. Indeed, Arabic *sukkar* is, directly or indirectly, the origin of most European names for sugar, like Spanish *azucar* (from Arabic *al sukkar* "the sugar"), Italian *zucchero*, itself continued by German *Zucker*, Swedish *socker*, or French *sucre*, while English *sugar* and Dutch *suiker* are derived from Old French. We recognize the same Arabic origin in Polish *cukier* and Finnish *sokeri* (borrowed from Swedish), while in Romanian, *zahăr* is related to Modern Greek *zakharê* "sugar".

N.B.: the Slovenian name *sladkor* "sugar" as well as the verb *sladkati* "to sweeten" belongs to a Balto-Slavic family of words (including Polish *słodki* "sweet") related to the Old Norse *saltr* "seasoned, salted" (Buck 1988), itself related to the Indo-European root meaning "salt." This shows that seasoning can be done with salt or with sugar!

2.2.1 *Sugar*, *Saccharide*, or *-ose*

We know *monosaccharides*, like glucose, *disaccharides*, like lactose, and *polysaccharides*, like cellulose where we see the suffix -*ose*, which is still another way for designating a sugar or a sugar derivative. This suffix comes from the name *glucose* itself, attested in a French publication in 1838. The decision has been to name the other sugars after *glucose*, like *fructose* (from Latin *fructus* "fruit"), *lactose* (from Latin *lac*, *lactis* "milk"), *galactose* (from Greek *gala*, *galactos* "milk"), etc. Glucose, fructose, lactose, galactose, etc., were called *oses* in French, the word *ose* itself becoming another synonym for *sugar* and *saccharide*. Then *polyose* will be roughly a synonym of *polysaccharide*. But we still have to explain *glucose*.

2.2.2 Mildness, Sweetness in Chemistry

The name *glucose* is borrowed from the Greek name *gleukos* meaning, in Aristotle's works, "mild wine" or, in a figurative sense, "mildness." Then, *gleukos* itself is derived from the Greek adjective *glukus* "mild, sweet, delicious" in the literal as well as the figurative sense. From these names, we have many derivatives with the prefix *glyc(o)*- or *gluc(o)*-.

- The prefix *glyc(o)*- is used for a sweet substance, like *glycine* itself, or *glycerin* (made from the Greek adjective *glukeros*, nearly a synonym of *glukus*), and then derivatives like *glycol*.
- The prefix *glyc(o)*- or *gluc(o)*- represents glucose or any glucose-like molecules; for instance (cf. terminology in Chap. 3):
  - *Glycan*, as a synonym of *polysaccharide*, or oligosaccharide, is made only of sugar units.
  - *Glycogen* is a polymer of glucose, which can deliver (generate) glucose.
  - But *glucan* is a polysaccharide made only of glucose units, like cellulose and starch for instance.
  - In French food terminology, *glucide* is the word for *carbohydrate*.

To conclude this paragraph, we can say that *glucose* is a sort of pleonasm because *gluc*- means "sweet, mild as sugar" and, in chemistry, suffix -*ose* is a synonym of *sugar*! In the same way, the name *saccharose* (or *sucrose*) is a pleonasm as well!

2.3 A Large Variety of "-oses"

Starting from *glucose*, the suffix -*ose* is added, for designating different sugar units, to several elements related to:

Fig. 2.1 *Sorbus domestica*. Sorb tree, or service tree, or rowan. BotBln, Feb. 17, 2012 via Wikipedia, Creative Commons Attribution

- A chemical structure as for *hexose* (six carbons) and *pentose* (five carbons), or *aldose* (aldehyde function) and *ketose* (ketone function)
- An optical activity as for *dextrose* (Latin *dexter* "right") and *levulose* (Latin *loevus* "left")
- And, more frequently, the vegetal or animal origin of the molecule, as in *fructose*, *lactose*, and *galactose* already mentioned, or *xylose* (Greek *xulon* "wood"), *maltose* (from *malt*), and *fucose* (from Latin *fucus* "red alga").

The name *sorbose* is derived from the genus name *Sorbus* of several plants like sorb trees or rowans (Fig. 2.1).

The *rhamnose* was isolated from the buckthorn, a plant belonging to genus *Rhamnus*, created by Linnaeus in 1753 after the Greek name of this plant, *rhamnos* (Fig. 2.2).

The origin of *apiose* is not obvious. Could it be Latin *apis* "bee"? Indirectly yes, since the apiose has been extracted from parsley, and then *apiose* comes from Latin *apium* "parsley." But Latin *apium* originally is the name of celery, so named from *apis* "bee," because it was considered in antiquity as the *herb of bees*.

The origin of *mannose* is still more enigmatic: it comes from *manna*, the Hebraic name in the Bible for the miraculous food appearing in the desert but, in reality, a sweet secretion provided by some trees or bushes in favorable conditions.

Arabinose was extracted from *gum arabic*, an excretion of several species of Acacia, mainly in

Fig. 2.2 *Rhamnus frangula*. Alder buckthorn. David Perez, Feb. 17, 2012 via Wikimedia. Creative Commons Attribution

Arabic-speaking regions of northern Africa. Later on, the name *ribose* was used (in 1892) for a new isomer of arabinose, the change of letters from *arabinose* to *ribose* being a sort of literal representation of the chemical isomerization (likewise, in the same period, an isomer of xylose was named *lyxose*).

In the following decade, researchers of the Rockefeller Institute of Biochemistry (RIB in New York City) showed the crucial role of ribose in the chemistry of life (as part of ribonucleic acid or RNA). By chance, the initials RIB could then also be read in *ribose*.

We come now to a polymer of "-oses" of major importance.

2.4 Cellulose

Roughly speaking, cellulose is polymerized glucose, and this is the reason of the suffix *-ose* of *cellulose*. The first part of the name means that this natural polymer is an important constituent of vegetal cells, namely, the main constituent of cell walls. The French name *cellulose* is originally attested in a botanic course of Antoine de Jussieu in 1840, after French *cellule* "cell," derived earlier from Latin *cellula* "small room," diminutive of *cella* "room" (the etymology of which is perhaps related to the Latin verb *celare* "to hide"). In other Roman languages, the name of a cell is also linked to the Latin diminutive *cellula*, like Italian *cellula*, Spanish *célula*, Romanian *celulă*, but in other languages, the name comes directly from *cella*: English and Swedish *cell*, German *Zelle*, Dutch *cel*, as well as in Finnish *solu* or Polish *cela* (Slovenian is different with the diminutive *celica* "cell"). Nevertheless, in all languages, the name of cellulose is equivalent to the French word: Italian *cellulosa*, Spanish *celulosa*, Romanian *celuloså*, as well as English *cellulose*, German *Zellulose*, Swedish *cellulosa*, Dutch *cellulose* (besides *celstof*, which, in Dutch, means "constituent of cell"), Polish and Slovenian *celuloza*, and Finnish *selluloosa*.

Now, before coming to starch, the other important natural polysaccharide in terms of volume, let's examine different ways of expressing sweetness in European tongues.

2.5 Indo-European Representation of Mildness or Sweetness

We have seen the Greek adjective *glukus* "mild, sweet." Its Latin equivalent is *dulcis*, becoming *dulce* in Spanish, *dolce* in Italian, or *édulcorant* "sweetener" and *doux* "mild" in French. Can we relate *glukus* to *dulcis*? Yes, if we consider (Ernout and Meillet 1985) the probable existence of an Indo-European root, **dluku-*, and if we admit that its initial *d* becomes *g* in Greek (by attraction of *k*, since *g* is closer to *k* than *d*) while the element *-lu-* of **dluku-* becomes *-ul-* in Latin (in linguistics, such an exchange of letters is called *metathesis*, and it happens that the same word, *metathesis*, designates a chemical reaction exchanging one atom group of one molecule with one atom group of another molecule). However, we see that English *sweet* is quite different, as well as *mild*. First, we have another Indo-European root, **swad-* "mild, pleasant," which explains:

- English *sweet*, German *süss*, Dutch *zoet*, Swedish *söt*

- But also Latin *suavis* "mild, pleasant," then *suave* in French, borrowed as such by English, *soave* in Italian, more in the figurative meaning

Now, we have to deal with the adjective *mild*, which belongs to a completely different family of words.

2.5.1 From *Millstone* to *Mildness*?

As a matter of fact, there are connections (Onions 1992), even if they are not firmly established, between:

- Greek *mulê*, Latin *mola* "millstone," Latin verb *molere* "to grind, to mill," then in English *to mill*, and result of milling which is *meal* "flour," like in *wheatmeal*, for instance (nothing to do with *meal* "lunch or dinner", which is related to *measure*), and in Dutch *meel* "meal, flour" and in German *Mehl* "flour."
- Latin *mollis* "soft," because a milled product is no longer hard, then French *mou* "soft" and *mild* "not hard," in English as well as in German, Dutch, and Swedish.
- The Germanic root represented by English *to melt* "to become liquid" (and the variant *to smelt* "to fuse" in metallurgy, Dutch *smelten* "to melt," German *schmelzen* "to melt") since both melted and milled substances are fluid.
- Finally, English *malt* (then French *malt*, German *Malz*, Dutch *mout*) has something to do with *melt*, since the malt is produced by a digestion of barley grains in water, resulting in a sort of syrup.

In this process, barley starch is depolymerized by amylase: this leads us to the history of starch names in different languages.

2.6 Starch

2.6.1 Starch in Greek, Latin, and Roman Languages

This product was named *amylum* in classical Latin, itself borrowed from Greek *amulon*, coming from *amulos*, the first meaning of which is "not ground, not milled." Indeed, *amulos* is made (Chanteraine 1990) of the privative prefix *a-* "without" and the name *mulê* "millstone." The reason of this etymology is that starch was prepared with fresh grains, without any milling, as opposed to flour. Pliny the Elder (first century), in his *Natural History* (Liber XVIII, 76), explains it as follows: "*The invention of starch happened in Chios island, and still today the most estimated one is coming from there. It is so named because it is prepared without the use of any millstone*." Of course, the production of starch has been much improved all along times: some crushing or grinding of the grains has been added in the process, and even milling, since the wheat starch can be produced today from flour. Nevertheless, the etymology of Latin *amylum* derivatives retains the footprint of the ancient process. In the medieval period, this name *amylum* was altered to *amidum*, whence the names of starch in Roman languages, like French and Romanian *amidon*, Italian *amido*, or Spanish *almidón*.

Let's make two remarks:

(1) The late Latin word *amidum* "starch" has nothing to do with the much more recent name *amide*. While *amidum* must be understood as *a* + *midum*, the name *amide* is made of *am* + *ide*, where *am-* is the beginning of *ammoniac*, since a molecule of amide is built around an atom of nitrogen. In the scientific nomenclature, no confusion can happen with *amide* since the starting point for expressing a relation with starch remains classical Latin in the prefix *amyl(o)-*, like in *amylose*, *amylase*, *amyloplast*, or, in French, *amylacé* "starchy."

(2) *Amyl-* is also synonym of *pentyl-*, like in *amyl alcohol*, probably because this alcohol can be produced from starch.

But then, what is the origin of *starch* in English, which is so different from the Latin form?

2.6.2 Starch in Germanic Languages and in Finnish

The English name of *starch*, as well as its equivalent in German, *Stärke*, or in Swedish, *Stärkelse*, is not related, as in Greek, to its manufacturing process but to its utilization. As a matter of fact, those names are related to the same Indo-European root as the adjective *stark*, in English "rigid, stiff" and in German and Swedish "solid, resistant," and this relation is due to the stiffness which is given to fabrics and clothes by the application of starch. Even more unexpected, the name of a famous bird, the *stork* in English and Swedish, *Storch* in German, is related to the same Indo-European root, just because this bird, so elegant while flying, looks stiff when it is landing and then walking on its nest. The name of the stork is totally different in Latin (*ciconia*, probably an onomatopoeic name, for this clattering bird), and then in the Roman languages (as *cigogne* in French). Coming back to starch, its name in Finnish, *tärkkelys*, is borrowed from Swedish *stärkelse*, with the fall of the initial s (cf. *Tukholma*, the Finnish name of Stockholm). Even if Finnish is not a Germanic language, and even not an Indo-European language, many borrowings happened between Finnish and Swedish all along the history of Finland.

N.B.: In this case, the Dutch names (van Veen 1989) are completely different from other Germanic languages:

- *Zetmeel* "starch" is made of *zet*-, meaning "making thick, setting," which is logical for starch in food use and of *-meel* "meal, flour," but the other Dutch name *stijfsel* "starch for nonfood use" is a derivative of *stijf* "stiff," which is logical for a stiffening product.
- *Ooievaar* "stork" is somewhat isolated and originally means "bringing luck."

2.6.3 Starch in Slavic Languages

The name of starch in Polish, *skrobia*, comes from the verb *skrobać* "to scrape," because starch has been produced from grated wheat grain and later on from grated potato or maize. In Slovenian, the name *škrob* "starch" is of the same origin. After cellulose and starch, a third important polysaccharide is chitin.

2.7 Chitin

The name *chitin* is attested (*chitine* in French in 1821) for designating the main constituent of the carapace of insects. This name, with the suffix -*in*, comes from Greek *khitôn*, which was used, in secondary meanings, for naming hard envelopes in anatomy and in botany.

This Greek name itself, probably of Semitic origin, designated originally a sort of tunic, generally short for men and long for women, still named *chiton* (in French too) in texts relating to antiquity. However, this Greek word took several derivates and other meanings, such as any item of clothing, an armored coat for a soldier, and, as we just said, the skin of animal organs, of snakes, or of fruit, or else the cork of some trees or the shell of mollusk shellfish.

Today, it is well known that chitin is the main constituent of carapace, not only of insects but of all arthropods, including particularly crustacean shellfish, and that it is also the main constituent of cell walls of fungi. Chitosan is obtained from chitin by partial deacetylation, resulting in the fact that chitosan is water soluble while chitin is not.

2.8 Other Polysaccharides

The last paragraph of this chapter will deal with the names of the following polysaccharides: *carrageenan*, *inulin*, *pectin*, *heparin*, *pullulan*, *hyaluronan*, *murein*, and *levan*.

2.8.1 Carrageenan

Carrageenan is extracted from red seaweed known under the common, and misleading, name of *Irish moss* or *carrageen moss* or *curly moss* (Fig. 2.3).

This English name *carrageen* (in French *carragheen*) probably comes from the old names (*Carrageen*, *Carragheen*) of the city now named *Carrigeen* (originally, in Irish *Carraigin*,