Pharmacognosy and Its Role in the System of Profile Disciplines in Pharmacy

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Abstract
The primal discipline from which pharmacy has developed can be considered as pharmacognosy. This review defines pharmacognosy while reflecting on the latest development and discourse about its justifiability in the educational system in pharmaceutical faculties and the history of development of new drugs under the influence of pharmacognosy. The article defines the status quo of the pharmacognosy area, or more precisely its parts (biology, chemistry, production, and technology) and discusses their connections. It underlines the legitimacy of application of natural drugs in therapy, which is undeniable, and proves that whether a new drug was prepared either synthetically or isolated from a natural source is not important. The overview follows the basic requirements of pharmacognosy, especially its methodology (usage of faster and more effective phyto-analytical methods, reverse pharmacology, and reverse pharmacognosy, in silico methods). Pharmacognosy is confronted by three major challenges in the 21st century that can push it significantly forward: ethnopharmacological sources evaluation, evaluation of nutraceuticals, and pharmacognosy of marine organisms. The educational system of universities should correspond to these new demands. However, in some areas the educational system is not prepared to face the challenges of the time. The basic requirement is to adopt a complex attitude to biogenic material and utilize the connections of this complexity in the teaching of modern pharmacy.

Keywords
pharmacognosy, historical development, subject justification, pharmacy education, profile disciplines, syllabus development

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Some consider pharmacognosy as an obsolete academic discipline and there are thoughts about how to deprive it of its status as a separate subject. This opinion is based on limited knowledge that reflects on recent developments in pharmacy, in which 2 disciplines seek to occupy the major position: first, pharmaceutical chemistry, which includes drug analysis, and second, pharmacology, which includes clinical pharmacology and clinical pharmacy. Without any doubt these disciplines play important roles in pharmaceutical activities, but, from the point of view of academic institutions, it is necessary to take into consideration the experience of historical development and the indisputable facts based on it, which cannot be overshadowed by any discussion. It is not that important whether a particular compound has been either isolated from a biogenous material or synthesized de novo, but emphasis is put on drug efficiency. In Europe, especially in German-speaking countries, pharmaceutical disciplines are divided into three basic categories: pharmaceutical chemistry, pharmaceutical biology, and social pharmacy. For individual categories this “division” can be understood as the creation of its own approach to the development of an educational system of pharmacy. Looking into the educational profile of the major world universities, we find that the teaching of pharmacy and pharmacology is malleable, but keeps features of basic pharmaceutical disciplines, especially in Europe and significantly in Asia.1

Definition of Pharmacognosy
To clarify the problem of the position of pharmacognosy in the basic pharmaceutical disciplines, it is necessary to approach the roots of the whole of pharmacy, which significantly go back to the beginning of human existence. In 1991, spectacular celebrations took place in the Federal Republic of Germany —750 years had passed since the enactment of the Frederick II “Constitutiones regni Siciliae 1231–1241,” which divided healing into two fields: medicine and pharmacy. This progressive

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decision enabled the development of both fields, side by side, and the declaration of their identity: the goal of medicine is diagnosis and treatment, the goal of pharmacy is the development, production, and distribution of the optimal medicinal product. At that very time, the foundations were laid for the formation of the oldest pharmaceutical discipline, pharmacognosy, from which pharmacy has developed.

In order to define the historical background and goals of pharmacognosy, it is essential to mention a valid definition (used in the Czech Republic): Pharmacognosy is a profile discipline of pharmacy studying natural products; its goal is to discover sources of natural drugs (plants, microorganisms, fungi, algae, animals) and products of their metabolism used and applicable for treatment, disease prevention, and diagnostics in human and veterinary medicine, to explain the biosynthesis of biologically active substances, possibilities and methods of their isolation, identification, technological modifications, and their classification according to their effect. In addition to the basics of structure determination, it must point to the possibility of partial synthetic changes resulting in the desire for either modification or alteration of action and also address recombinant techniques to obtain drugs from genetically modified organisms. This definition is based on pharmaceutical history and proves that pharmacognosy is a polyhistorical science. The American Society for Pharmacognosy defines pharmacognosy as “the study of the physical, chemical, biochemical, and biological properties of drugs, drug substances, or potential drugs or drug substances of natural origin, and the search for new drugs from natural sources.” Such a strict definition taking into account the development of pharmacognosy in the 20th and 21st centuries may be considered somewhat narrow.

**Historical Development**

Badal and Delgoda reported in 2017 that the term “Pharmacognosy” has been used for the first time between 1811 and 1815 by Schmidt and Seydler; at that time, the term was intended for *Materia medica* (a set of medicinal products used in practical therapy). These were mainly medicinal drugs of plant, fungal, and animal origins (medicinal drug means dried or otherwise preserved biogenic material, usually standardized, which is intended for therapeutic purpose in the same or refined form or serves as a source for the isolation of medicinal substances), and, on a smaller scale, for chemically uniform drugs (inorganic salts, exceptionally synthesized substances). The history of pharmacognosy beginnings has been compiled in an instructive review. At the beginning of the 19th century nothing more could be expected from the field, except for commodity knowledge accompanied by control of identity and quality by methods at the level of the time. At that time, the foundations of future pharmacology already existed, which later proved to be an important profile discipline (although the use of *Materia medica* was still based on empirical experience). It is obvious that pharmacognosy was, therefore, very closely connected with pharmacology in pharmaceutical faculties until the first half of the 20th century. Both synthetic and analytical chemistry also began to develop in the 19th century; pharmacognosy was developing side by side with drug chemistry until the end of the century; all these disciplines contributed with their knowledge to *Materia medica*; the decades from 1830 are the period of the beginning stage of chemical drug development; this got very rapid after the fall of the vitalist theory of Wöhler’s synthesis of urea, and its progress did not stop and preceded the development of pharmacognosy for understandable reasons: biogenic material is a complex mixture of primary and secondary metabolites that must be isolated and their structure identified. However, the instrumentation of that age did not allow this. On the other hand, controlled synthesis was much easier. Nevertheless, some of the synthetic substances were based on a natural model (eg, acetylsalicylic acid from salicylic acid, whose precursors were obtained from willow bark). At the beginning of the 19th century, the first chemically uniform drugs (eg, morphine, quinine, and emetine) were isolated from medicinal plants, but their derivatives were not yet discovered. The paths of both disciplines seemed to diverge, only to merge later. Pharmacognosy developed independently, according to circumstances, and continued in such form until the 20th century, through both world wars. However, at the end of World War II, the discovery of penicillin and its acquisition showed that separation and structural analysis methods were developing promisingly, and alongside them, pharmacognosy. Nevertheless it took another quarter of a century before pharmacognosy became a discipline with a promising path to modernity, in which cannot be overlooked the analytical phytochemistry of Prof. Egon Stahl of Saarbrücken University, the extensive work of American pharmacognosists in finding sources of steroid saponins in the United States and South America, or the screening of natural substances at the National Cancer Institute, Bethesda, USA, which resulted in vincristine, etoposide, teniposide, and paclitaxel. Pharmacognosy is expanding its scientific working apparatus and has accepted knowledge from several other scientific disciplines that have significantly enriched it in terms of studying natural materials. Since separating from pharmacology in the 1950s, pharmacognosy has become an important pharmaceutical entity, utilizing increases in advances in analytical and preparative chromatography, spectral methods, genetics, biotechnology, agrotechnics, and industrial production processes, which have enabled it possible not only to isolate and identify many microbial, plant, and animal metabolites, but also to design and implement them as drugs on an industrial scale. By this stage the subject has come to the same point as pharmaceutical chemistry: a new drug is emerging. The rivalry between these 2 disciplines has proved unjustified: the idea that any natural substance can be synthesized without the need for pharmacognostical investigation is wrong, but unfortunately the rivalry still persists. It is usually not the pharmacist, but the chemist, who holds this false opinion. Total synthesis of steroidal hormones (Woodward, Robinson 1951), structure of vitamin B₁₂ (Todd, Hodgkin, 1955), synthesis of ergotamine (Stoll 1961) and vitamin B₁₂ (Woodward, 1972),...
structure elucidation and synthesis of endorphins (Hughes, Kosterlitz, 1975) and many others have been and are encouraging, but forcing us to ask: at what cost? Although with important drugs (eg, bisindole alkaloids vinblastine, vincristine) there have been stimulating studies on their total synthesis, in which a number of compounds have been found with higher biological activity than the desired alkaloids alone, there are currently no reports of the use of these methods for real alkaloid production. The same is the case for paclitaxel, for which total synthesis is known, but of little practical use, and, therefore, the Bristol Myers Squibb semisynthetic procedure using deacetylbaeacatine III from needles of yew taxa. These facts have been very stimulating for pharmacognostical research in the spirit of the definition that has been stated—the preparation of partial derivatives. It would be useless to live with the idea of the synthetic nonpharmaceutical chemist that any natural substance can be produced by total synthesis. In some cases, we cannot reject, but most of the time it is paradoxical: biogenic material is a renewable raw material, and using modern isolation and separation methods it is possible to prepare these substances more cheaply (if we include employment and ecological impact).

Pharmaceutical chemistry, in the 1980s already a fully integrated pharmaceutical discipline, had the idea that the predominant methods for obtaining optimal drugs would be in silico methods: chemical docking, QSAR, and others. These methods are undoubtedly important and necessary; many synthetic and semisynthetic drugs have been developed using them, but they are not unambiguous, and we know from our own experience that the results of computer modeling sometimes differ interestingly from the reality in determining the biological activity of substances, and, therefore, it is necessary to use more complex methods. In this field, where pharmacognosy encounters pharmaceutical chemistry, it must be stated that pharmacognosy has a major advantage in that it is mostly based on ethnobotanical or ethnomedical knowledge, which has been tested over a long period of time. If we look at the history of pharmaceutical chemistry, we can see that the chemistry of drugs in the 19th and 20th centuries is based on natural models.

### Status Quo: Areas Affecting Pharmacognosy

In order to be able to assess the validity of pharmacognosy as an academic (educational) and practical field at present, it is necessary to name the areas included in pharmacognosy either fully or to some extent:

#### A. Biological disciplines
- **Pharmacognosy sensu stricto** (basic verification methods, microscopy, microscopy),
- **Pharmacobotany** (ethnobotany, physiology, and biochemistry of secondary metabolites),
- **Genetics** (creation of chemical varieties by gene recombination for field production),
- **Biotechnology** (microbiology, production of substances, by various cell types in vitro, usage of recombinant DNA technologies, enzymes fixed to a carrier),
- **Pharmacology and toxicology of natural substances** (basic characteristics of biological effect, primary toxicity of newly isolated compounds, detection of undesirable impurities).

#### B. Chemical disciplines
- **Isolation phytochemistry** (optimal procedure for obtaining active substances),
- **Analytical phytochemistry** (qualitative and quantitative analytical chemistry of natural compounds),
- **Preparative organic chemistry** (preparation of derivatives and structure modification of isolated compounds),
- **Structural analysis methods**.

#### C. Production of raw materials
- **Production of biogenic material** (agrotechnics, field production),
- **Technology of natural drugs** (processing of biogenic raw materials, substances isolation on an industrial scale).

#### D. Technical disciplines
- **Computer methods** (chemical docking),
- **Cataloging and classification of natural raw materials**.

The sum of all these disciplines, most of which are preparatory, creates the whole of pharmacognosy and it is unimaginary to single out any one of them. This is clearly demonstrated by data in the literature regarding the concept of pharmacognosy, including forensic pharmacognosy, ecopharmacognosy, and molecular pharmacognosy as emerging areas of the subject; this is a response to the ongoing process of unambiguous verification of medicinal drugs based on their genetic profile (DNA) and subsequently the metabolome. It also offers the application of molecular techniques in monitoring the quality of biogenic material and computer-aided methods for monitoring the metabolome of natural sources. Classical pharmacognostical methods are still being streamlined, which have effective results when the appropriate use is known.

### Justification of Natural Substances at Present

The importance of natural products in therapy is clear from the analysis of the number of drugs containing these substances and drugs derived from natural formulas, which are included in the List of Basic Medicinal Products of the World Health Organization. The 13th revision includes nearly 300 different drugs considered essential for medical practise, including approximately 210 small-molecule drugs. These include 44 unmodified natural products, 25 semisynthetic derivatives of natural products, and more than 70 synthetic drugs based on pharmaceuticals containing natural substances or synthetically modified structures of natural origin. In the review, the definition of the origin of natural substances follows the convention used by Newman, Crag, and Snader.
considering the history of their development and the origin of the relevant drug prototypes.\textsuperscript{19,20} A detailed overview of the turn-of-the-century area is provided by Jones et al.\textsuperscript{21} These authors are of the opinion that medicines derived from natural sources (directly or indirectly) make up about half of prescription medicines and are likely to continue to do so in the future, as about half of the new chemical entities entering the new medicine approval process are either natural products or related compounds. The importance of natural products in modern medicine is not just a remnant of the shared history of medicine and vegetable drugs from nature. Natural products are an excellent source of chemically diverse lead structures for discovery of new drugs. In addition, products based on biogenic material are an important part of modern medicine and pharmacy, and research of natural medicines (especially with regard to determining their active principles and mechanisms of action) by pharmacognosists and other specialists in natural products is essential for these products to remain part of the modern therapeutic environment.

An instructive overview of the current state of pharmacognosy is given by Alamgir,\textsuperscript{22} whose views we have taken into account.

### Pharmacognosy in the 21st Century

At present, it must be stated that the general interest in pharmacognosy is still high. In the last decade, there has been an increasing use of biogenic resources compared to previous decades. Simultaneously more people trust medicinal products. The portfolio of these products in world pharmacy is increasing and there is also increasing interest in this area among the students of pharmacy. In some countries, phytopharmaceuticals (and phototherapy) are still an integral part of the curricula of pharmaceutical faculties, and interest in these components of natural remedies is also growing in the scientific community. There is increasing scientific interest in the components of natural medicines and nutraceuticals, increasing funding opportunities, but also increasing competition from those working in fields outside of academic pharmaceutical institutions and interested in profiting in this field, as they see it as a mainstay. Pharmacognosists have valuable knowledge that can be extremely useful in the process of discovering new medicinal drugs. The solution of new projects, which will be developed in the future, can be considered as more complex than in the 20th century, with the growing representation of scientific disciplines and their development. It is to be hoped that, as pharmacognosy research becomes more specialized, it will find a strong and coherent presence at national and international gatherings and ensure that pharmacognosy as a field will not disappear. Work on the development of pharmacognosy should involve people with the widest possible professional background with new development trends at the forefront, such as combinatorial synthesis, genomics, and proteomics. Researchers (and academics) in the field of natural substances will be required to be more flexible than ever before, but thanks to new procedures and tools available, the benefits will be much greater in terms of their own scientific interest and for society than before. There is no doubt that pharmacognosy can look to the future with great anticipation.\textsuperscript{23}

As early as the end of the 20th century, it was clear that pharmacists with comprehensive education, inventiveness in drug research, and improvisation skills provided by their academic education in all areas of pharmacy were to play a leading role in pharmacognosy.\textsuperscript{24}

Pharmacognosy currently faces three new challenges that have not been practically applied before:

- The first is the evaluation of medicinal drugs of ethnic groups, which are used in medicinal products and are based on cultural tradition and in which the therapeutic system is not based on receptor theory (principles of traditional Chinese medicine [yin-yang], traditional Indian medicine [Ayurveda], traditional Japanese [Kampo], and Mongolian medicine [Domi]).

- The second challenge is the role and position of pharmacognosy in the evaluation of biogenic material (extracts and pure substances), as well as preparations that do not have a legally binding character of the drug, but are nutraceuticals, dietary supplements, or novel foods. Although these are special foods for which no therapeutic indication must be given, they play an increasingly important role in therapy and must be assessed. The products have not only great economic impact on pharmacies, but also practical ones: nutraceuticals are often used as part of controlled therapy, sometimes even in self-medication as the therapeutic agent itself. The situation is still complex and needs to be addressed by legislation (certain processes are ongoing at EU level). Expert opinion must be based on pharmacy-pharmacognosy and must not be replaced by political opinion. The problem of nutraceuticals, even if they are foods, must be approached accordingly based on modern knowledge.\textsuperscript{25}

- The third challenge is the pharmacognosy of marine organisms. The use of these was first mentioned 50 years ago,\textsuperscript{26} and its deeper development took place about 40 years ago (eg, in Sweden).\textsuperscript{27,28} The full breadth of this area of pharmacognosy is shown by a number of publications.\textsuperscript{29,30} As part of their academic studies, pharmacist-pharmacologists must be professionally prepared in their studies to use modern methods of their time, which enable success in the isolation of macromolecular substances with unusual effect\textsuperscript{31}; the major part of pharmacognosy still involves small-molecule substances, which are much easier to handle.

Reverse pharmacognosy, together with reverse pharmacology, plays an important role in modern pharmacognosy: they focus on finding targets for natural substances through either virtual or real screening and identifying natural resources that contain active molecules. Techniques used include...
high-throughput screening (HTS), virtual screening, and knowledge databases containing traditional plant uses. Classical pharmacognosy uses plants to discover new bioactive compounds, while reverse pharmacognosy uses natural metabolites to find potentially new therapeutic properties of natural material. The integration of pharmacognosy and reverse pharmacognosy into the research process can provide an effective and rapid tool for the discovery of new drugs.32,34

Reverse pharmacology35 (also known as target-based drug discovery, TDD)36 is based on two processes: first, it is hypothesized that modulation of the activity of a specific protein target will have beneficial therapeutic effects. Subsequently, studies in small-molecule chemical libraries are used to identify compounds that have a high affinity with the target. The results of this screening are used as starting points for the discovery of drug candidates. This method has become popular for sequencing the human genome, which has enabled rapid cloning and synthesis of large numbers of purified proteins and is currently the most widespread in the field of drug research.37

In contrast to classical pharmacology, the effect of in vivo identified active compounds is predicted by the reverse method, usually only in the final stages of drug discovery with a reverse pharmacological approach. It is also very important for the assessment of natural substances.38

Pharmacognosy in the Educational Systems of Universities

For the modern pharmacist, knowledge of traditional medicines is as important as modern trends in the development of pharmaceutical sciences. All these findings and knowledge are the basis for very; important drugs with a huge economic impact, for which the Nobel Prize is also awarded (Tchu Jou jou in 2015 for quinghaos-artemisinin). Pharmacognosy is not the subject of the past, even at this time of significantly bioligized pharmacy. Its development is plastically adapted to the fast-changing academic and commercial environment and succeeds in facing the challenges of the present in terms of the discovery of new drugs. This fact is undeniable from the list of professional literature, but it can be positively applied only in the case of a broader academic consensus in the educational system of pharmacy.

Although in the educational system of some countries, including the USA, we may not encounter the term “pharmacognosy” in the pharmacy curriculum, the field is de facto included in other disciplines, such as drug discovery from natural products, phytotherapy, herbal therapy, natural medicines, and phytopharmaceuticals.

However, the popularity and use of pharmacognosy is growing, significantly in countries with strong economies and pharmacognostical research (for which it is necessary to obtain erudite experts), which has gained new momentum, as it offers the opportunity to contribute with large sums for development. From a historical perspective, natural substances and their derivatives have provided several clinically useful drugs. However, once pharmacognosy does not have a comprehensive position in the educational system, complications can occur, as a review study from the United Kingdom (1997) shows, mainly from the point of view of academic research: only a few of the then 16 pharmaceutical higher education institutions had significant expertise in pharmacognosy. The reasons are complex and to some extent are due to the absence of phytotherapy in traditional medicine in the country. There has been a large increase in herbal medication in recent years, but due to the general lack of pharmacognosy teaching, many pharmacists know little about the products they provide in pharmacies. The multicultural nature of modern Britain has also increased interest in herbal medicines from India and China, further complicating the situation. In addition, pharmacognostical research is carried out in nonpharmaceutical institutions and pharmacists must intensively fill this gap in their education.39

As shown above, pharmacognosy is a valid pharmaceutical discipline that has a firm place in the curriculum of master’s and doctoral studies in pharmaceutical faculties. Time brings new perspectives in understanding the role and state of pharmacy and medicine, which forces us to adopt a rational attitude to create an optimal educational system. Without any doubt, pharmacognosy should have a permanent connection with pharmacology (the concept of reverse pharmacology has already been discussed) and pharmaceutical chemistry (which brings new possibilities in computer data processing and drug synthesis procedures, or preparation of modified structures of natural substances). There are several review studies that evaluate the development of pharmacognosy and its trends. From the profile of representative works, we consider it necessary to mention only two of them. The first is the already mentioned Alamgir’s communication, dealing with the development of mainly classical aspects of pharmacognosy in modern times.22 The opinions of Jones et al must also be considered important,21 which speak of new trends and prospects for pharmacognosy; despite significant successes, its traditional isolation and biological testing approach to the discovery of new drugs has its own limitations in a certain time-consuming nature. This problem may disadvantage approaches to the study of natural substances in the current environment, and, therefore, new strategies must be put in place to make natural substance research fully compatible with HTS. Various approaches are offered for such activities, which were partly mentioned, such as screening libraries of natural substances (molecular libraries), including reevaluation of the concept of “inactive compound,” more efficient processes of isolation and clarification of substance structure, use of modern spectroscopic methods and biological tests, improvement of chromatographic technologies (eg, hyphenation techniques and modern extraction methods) and in silico methods (“virtual screening”), and paying more attention to the analysis of synergy of activity between the components of the extract, which significantly contribute to the effect of many drugs and extracts. However, there are very few cases of systematic identification of the exact components of a crude natural product extract that act synergistically. The authors reiterate that medicines derived from natural sources (directly or indirectly) account for about half of prescription medicines and are very likely to continue to do so.
The importance of natural substances in modern medicine is therefore not a “remnant” of the shared history of medicine and natural remedies. It is essential that this process and these products remain part of a modern therapeutic process.

Steinhoff, whose rational opinion should be accepted, spoke appropriately about the future of pharmacognosy in the academic education system. How pharmacognosy should define its position in academic education and research is being discussed recently and the outcomes are already available in several European countries. The need for modernization in line with scientific and technological progress is indisputable, but it turns out that the primary knowledge of classical pharmacognosy cannot be set aside in the pharmacist’s curriculum. Pharmacognosy has always been an integral part of the academic education of pharmacists. In history it used to be a classical view of natural material (mostly plants), and it cannot be overlooked, but in the last 20 years it has become necessary to submit to new development trends. This knowledge forms the basis of scientific phytotherapy and the use of products that have been fully recognized as medicinal products under European legislation (eg, in accordance with European Directive 2004/24/EC, the Committee for Herbal Medicinal Products—HMPC—was established in 2004 and registration procedure for traditional herbal medicinal products), which is paramount for the pharmacist’s practical activities. There seems to be a consensus on the importance of pharmacognostical study with regard to the basic skills of future pharmacists, knowledge of medicinal plants, and expertise in the use of herbal medicinal products. The European Scientific Cooperative on Phytotherapy (ES COP) is of the opinion that the core competences of academic education must refer to biogenic substances as a whole; we mentioned this breadth in the introduction of this article. Academic education, which would focus only on modern scientific trends in the field of chemical drugs, would theoretically enrich the pharmacist, but would reduce his/her ability to identify medicinal plants with their components and their pharmacological effects and therapeutic efficacy. Only a balanced modern pharmacognosy that truly defines its own position in the teaching of pharmacists can succeed, and in addition it will find its place among other profile areas of academic education of pharmacists, such as pharmacology, pharmaceutical chemistry, and technologies, which it can enrich. However, it must not succumb to the idea of “merging” with other disciplines, but rather to retain the uniqueness of knowledge about medicinal plants and the necessary approach to their presentation and dissemination.

Conclusion

Each discipline is as strong as its definition is true and credible, as long as it can enforce it on the basis of economic and internal political possibilities and personnel-inventive workers. The teaching profile is a matter of not only a real need, but also the consensusal process of the university staff involved, who create this profile and there are always animosities in such a process.

If there are one-sided opinions, stemming from ignorance or prejudice, then the development of any field is significantly hampered. We may only desire that these antagonistic conflicts are as small as possible in terms of pharmacognosy and its application in the educational system of the pharmacist.

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References

1. Top Universities: Pharmacy and Pharmacology. https://www.topuniversities.com/university-rankings/university-subject-rankings/2018/pharmacy-pharmacology
2. Accreditation protocol. Pharmacognosy for Charles University, National Accreditation Office for Universities, Ministry of Education, Youth and Sports of the Czech Republic, Prague, NAU-518 / 2018-9, 2 pp. + 19 pp. attachment.
3. Sarker SD. Pharmacognosy in modern pharmacy curricula. Pharmacogn Mag. 2012;8(30):91-92. doi:10.4103/0973-1296.956545
4. Badal S, Delgoda R. Pharmacognosy: Fundamentals, Application and Strategy. Elsevier; 2017.
5. Hocking GM. Dictionary of Natural Products. Plexus Publishing. Inc; 1997.
6. Schneider W. Geschichte der Pharmazeutischen Chemie. Verlag Chemic; 1972.
7. Melichar B, Čeladník M, Hard J, et al. Chemická Léčiva. Avicenum; 1987.
8. Sears JE, Boger DL. Total synthesis of vinblastine, related natural products, and key analogues and development of inspired methodology suitable for the systematic study of their structure-function properties. Acc Chem Res. 2015;48(3):653-662. doi:10.1021/ar500400w
9. Nicolau KC, Guy RK. The total synthesis of paclitaxel by assembly of the ring system. In: Gouda IG, Iwao O, Dolattrai MW, eds. Taxane Anticancer Agents. American Chemical Society; 1994:302-312.
10. Badal S, Byfield G, Brown MC, et al. Chapter 3 - Areas of science embraced by pharmacognosy: constituent sciences of pharmacognosy. In: Badal S, Delgoda R, eds. Pharmacognosy. Academic Press; 2017:31-44.
11. Chester K, Tamboli E, Paliwal S, Ahmad S. Significance of molecular markers in pharmacognosy: a modern tool for authentication of herbal drugs. *Drug Dev Deliv Therap*. 2016;7(2):96-106.

12. Heinrich M, Anagnostou S. From Pharmacognosia to DNA-based medicinal plant authentication – Pharmacognosy through the centuries. *Planta Med.* 2017;83(14/15):1110-1116. doi:10.1055/s-0043-108999

13. Butt J, Arshad S, Mir Z, et al. Application of molecular techniques in quality control of drugs of natural origin; a review. *J Pharm Res Int*. 2017;20(6):1-18. doi:10.9734/JPRI/2017/38523

14. Allard P-M, Bisson J, Azzollini A, et al. Pharmacognosy in the digital era: shifting to contextualized metabolomics. *Curr Opin Biotechnol*. 2018;54:57-64. doi:10.1016/j.copbio.2018.02.010

15. Bakiri A, Plainchont B, de Paulo Emerenciano V, et al. Computer-Aided Dereplication and structure elucidation of natural products at the University of REIMS. *Mol Inform*. 2017;36(10):1700027 doi:10.1002/minf.201700027

16. Pharmacognostical studies. *Prog Drug Res*. 2016;71:5-10.

17. World Health Organization. Accessed November, 2005. http://whqlibdoc.who.int/hq/2003/a80290.pdf

18. Newman DJ, Cragg GM, Snader KM. Natural products as sources of new drugs over the period 1981-2002. *J Nat Prod*. 2003;66(7):1022-1037. doi:10.1021/np030096l

19. Witiak DT. *Drug Prototypes and their Exploitation By Walter Sneader*. John Wiley and Sons Ltd; 1996.

20. Dewick PM. *Medicinal Natural Products: A Biosynthetic Approach*. 2nd ed. John Wiley and Sons; 2002.

21. Jones WP, Chin Y-W, Kinghorn AD. The role of pharmacognosy in modern medicine and pharmacy. *Curr Drug Targets*. 2006;7(3):247-264. doi:10.2174/13894506776054915

22. Alamgir ANM. *Therapeutic Use of Medicinal Plants and Their Extracts: Volume 1: Pharmacognosy*. Springer International Publishing; 2017.

23. Douglas Kinghorn A, Kinghorn DA. Pharmacognosy in the 21st century. *J Pharm Pharmacol*. 2001;53(2):135-148. doi:10.1211/002235701775334

24. Opletal L, Opletalová V. Lék a jeho vývoj v dějinách (Drug and its Development in the History). Karolinum; 1999.

25. Kim D-M, Cha E-C, Chung K-J. Pharmacognosy for Korean medical food in the 21st century. *Prev Nutr Food Sci*. 2005;10(1):95-102. doi:10.3746/jfn.2005.10.1.095

26. Youngken HW. The biological potential of the oceans to provide biomedical materials. *Lloydia*. 1969;32(4):407-416.

27. Nilan TJ, Raveendran R. Marine pharmacognosy. *Int J Appl Biol Pharm Sci*. 2016;7(4):107-117.

28. Bohlin L, Cárdenas P, Backlund A, Göransson U. 35 years of marine natural product research in Sweden: cool molecules and models from cold waters. *Prog Mol Subcell Biol*. 2017;55:1-34. doi:10.1007/978-3-319-51284-6_1

29. Martin DF, Padilla GM. Marine Pharmacognosy; Action of Marine Biotics at the Cellular Level. Academic Press; 1973.

30. Kim SK. *Marine Pharmacognosy: Trends and Applications*. CRC Press; 2012.

31. Zhang Y, Phipps LB, McDaniel J. Pharmacognosy, a classical theme tuned to a contemporary melody. *Am J Pharm Educ*. 2017;81(8):5953. doi:10.5688/ajpe5953

32. Saeidnia S, Gohari AR, Manayi A. Reverse pharmacognosy and reverse pharmacology; two closely related approaches for drug discovery development. *Curr Pharm Biotechnol*. 2015;3(4):320-323.

33. Parikh H, Gohari AR, Manayi A. Reverse pharmacognosy and reverse pharmacology: two closely related approaches for drug discovery development. *Curr Pharm Biotechnol*. 2015;3(4):320-323.

34. Takenaka T. Classical vs reverse pharmacology in drug discovery. *BJU Int*. 2001;88(suppl 2):7-10. doi:10.1111/j.1464-410X.2001.00112.x

35. Lee JA, Uhlik MT, Moxham CM, Tomandl D, Sall DJ. Modern phenotypic drug discovery is a viable, neoclassic pharma strategy. *J Med Chem*. 2012;55(10):4527-4538. doi:10.1021/jm201649s

36. Swinney DC, Anthony J. How were new medicines discovered? *Nat Rev Drug Discov*. 2011;10(7):507-519. doi:10.1038/nrd3480

37. Patwardhan B, Chaguturu R. Innovative Approaches in Drug Discovery: Ethnopharmacology, Systems Biology and Holistic Targeting. Elsevier Science; 2016.

38. Houghton PJ. Pharmacognosy in the United Kingdom. *Pharm Pharmacol Lett*. 1997;7(2/3):45-49.

39. Steinhoff B; ESCOP Scientific Committee. The future of pharmacognosy in academic education. *Phytomedicine*. 2013;20(12):1047. doi:10.1016/j.phymed.2013.06.013