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Drawings and Micrographs:

Complementary Ways of Depicting the Biological World

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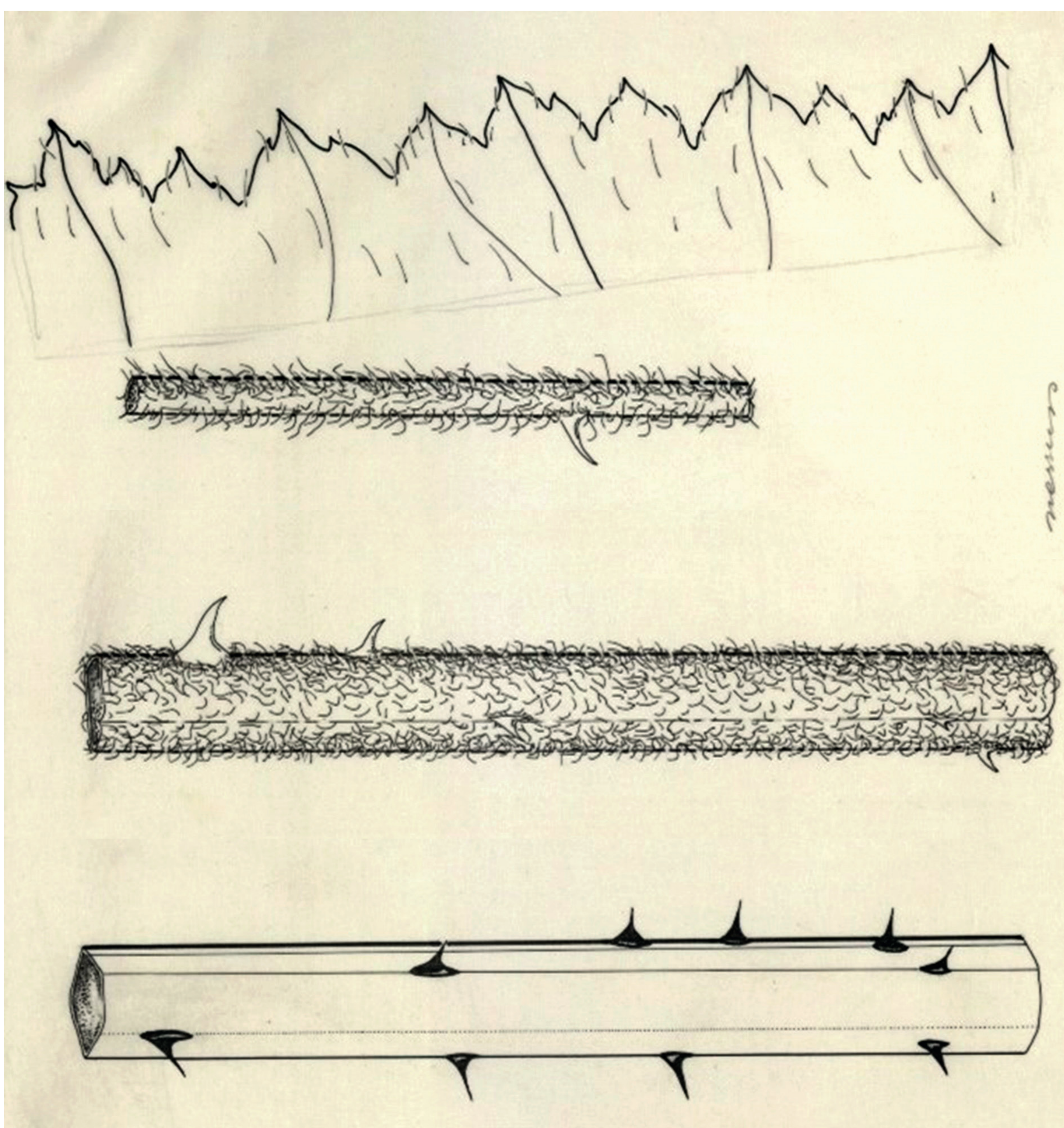

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The morphology of fragments of *Rubus nessensis*: apex leaf margin, peduncle, inflorescence axis, and vegetative shoot

How can the world of plants best be depicted? How do drawings differ from micrographs? Why is it that even the best quality photographs are no match for hand-drawn illustrations?

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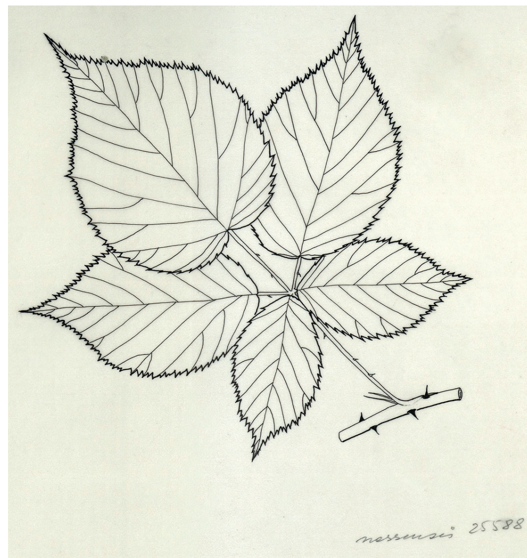
To understand and describe the world of organisms has been the mission of the biological sciences ever since their inception long ago. To write of "organisms" alone tempts us to add the adjective "living." Yet of course it is clear that we cannot omit organisms that are already extinct. In the natural sciences, understanding and description have always been closely associated with visual imagery. Morphological differences between various species are, for example, better shown by a single good illustration than even the most exhaustive verbal description. As long ago as the Middle Ages, descriptions of medicinal plants were accompanied by drawings or paintings. They may look imperfect through our modern eyes, but they did show the essence: that which is most important. Today, however, imaging techniques have become so advanced and refined that some doubt the point of still making drawings.

Between film and paper

Though photography is ubiquitous, drawing remains one of the primary methods of representing biological specimens. Why is this? If a plant or animal can be illustrated by a photograph, which would seem the perfect solution as no morphological detail is overlooked, why has photography not replaced drawing in academic papers and textbooks at least?

The truth is, a biological drawing (which here means not just any illustration related to biology, but rather a hand-made drawing specifically meant to reflect the structure of an organism) is simply not the same as a photograph, regardless of the technique in which it was made. An illustrator knows which elements of morphology are of particular significance and is able to bring them out in the drawing. It is therefore not a question of faithfully depicting all the



Leaf of the vegetative shoot of *Rubus nessensis*

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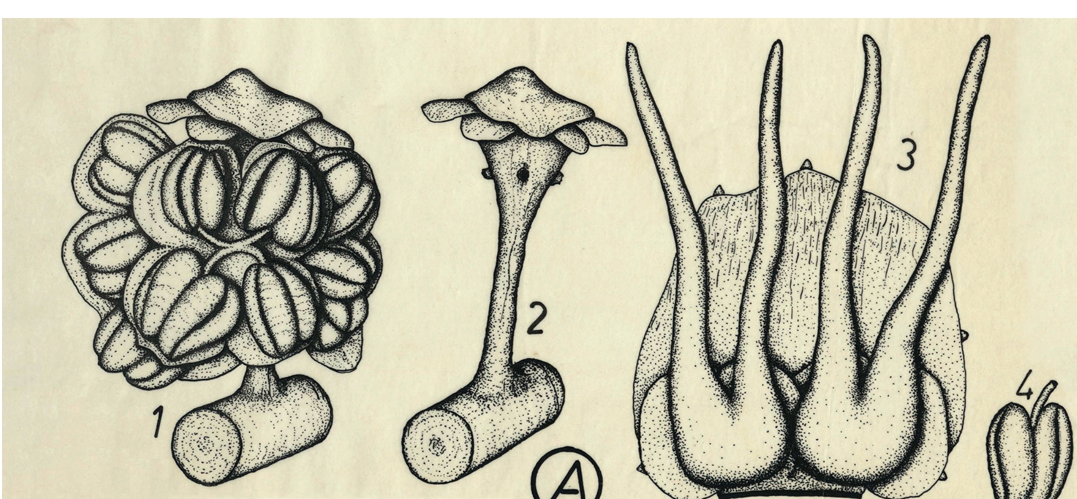

Fragments of the flower and fruit morphology of the black alder (*Alnus glutinosa*)

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details, but of focusing on the essential ones while leaving aside other details deemed unnecessary to render the subject properly. Drawings hold the advantage over photographs in the sense that a certain kind of filter is applied – made up of knowledge that can only be acquired through a profound understanding of the object studied. If the object is the stem of a plant that has characteristic features, such as barbs or small prickles, they may not be prominently shown in a photograph, but instead merge into the background with other elements of the morphology. A careful illustrator, meanwhile, can, while remaining faithful to the image of the object, highlight what is particularly significant and worth noticing in a drawing. In this way, an illustrator chooses the detail that means something to them – the detail they know is important.

This "they know" carries an especially powerful meaning: the illustrators know because they study their subjects at length, select the important elements and know what they can and should omit. It is in this "they know" that the very essence of drawing lies. It is a trait of researchers too – in the way that they arrive at conclusions and demonstrate or establish something. Illustrators without this "they know" can, at most, try to faithfully portray the visual image, possibly focusing on features of little importance and therefore not bringing out the essence. In its use of simplified forms, drawing makes it easier to discern what is important. In this way, it functions as an ideal summary of the essence of an object.

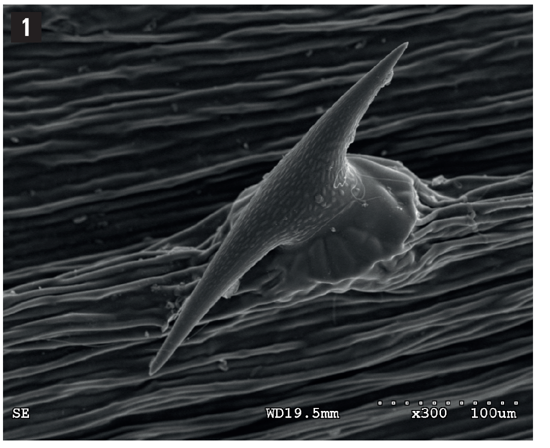

Photo 1
A two-armed, hooked trichome on a hop stem (*Humulus lupulus*); it performs a clinging function making it easier for the plant to climb up the support – SEM (scanning electron microscope) image

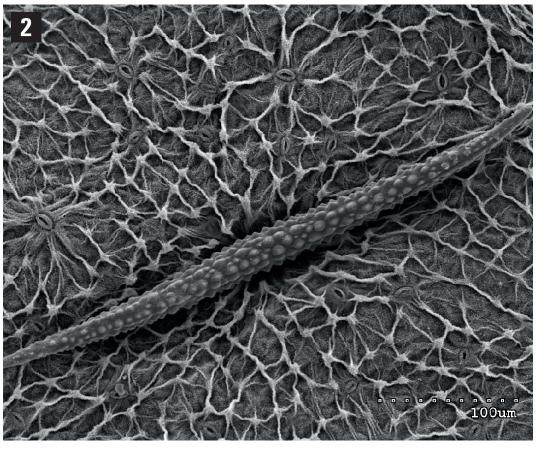

Photo 2
Two-armed, nodule-covered trichome on a leaf of red-barked dogwood (*Cornus alba*) – epidermis with characteristic cuticle folds – SEM image

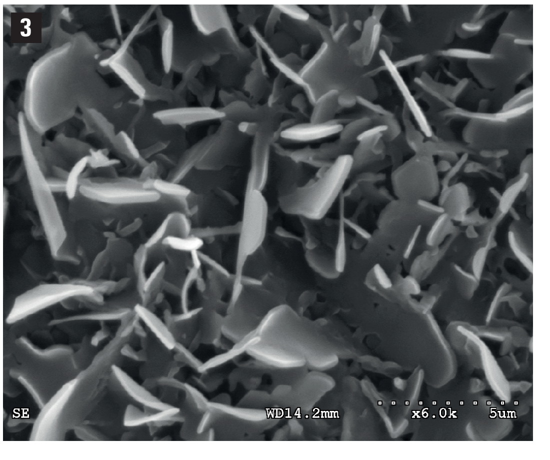

Photo 3
Wax plates on the surface of a stem of white dock (*Rumex triangulivalvis*) – SEM image

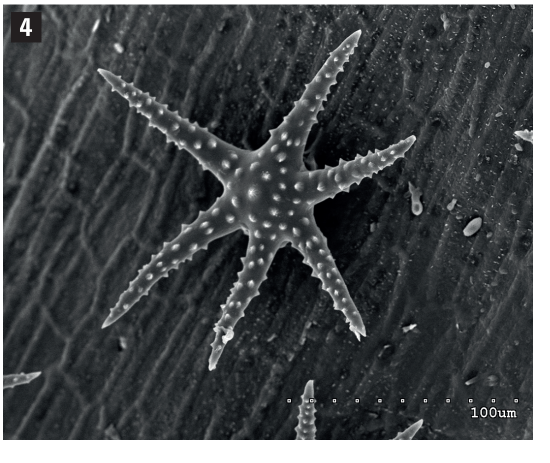

Photo 4
Branched (stellate) trichome on the stem of fuzzy deutzia (*Deutzia scabra*) – SEM image

Still needed

Books and scientific journals offer ample evidence that the importance of drawing in modern biology appears unshaken. It is enough to consult the latest Polish edition of *Dendrologia*, plant anatomy textbooks, identification keys or floras (publications that contain lists of plant species from specific areas with descriptions of structure, species distribution and keys to their identification). By drawing attention to important features and illustrating them, drawings form an entirely natural part of these publications. The same applies to journal articles presenting descriptions of new species and to systematic botany monographs. Nevertheless, with the spread of high-quality digital photography, the art of making a good drawing using traditional methods is gradually disappearing among biologists. Some hope can be placed, paradoxically, in the development of digital techniques, or more specifically drawing tools, as they simplify the otherwise laborious rendering of morphological details. It is easier to remove newly drawn lines on a tablet screen by undoing the operation than to erase lines made with a pen or even fine pencil strokes.

Drawings bring out important features and highlight characteristic details because they represent the

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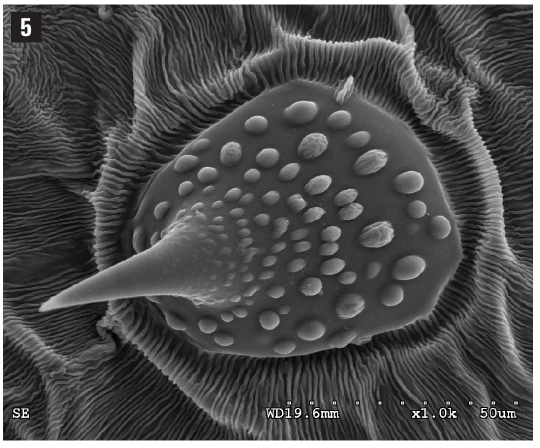

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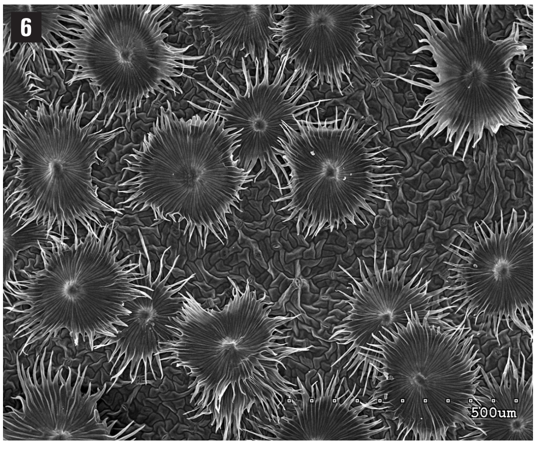

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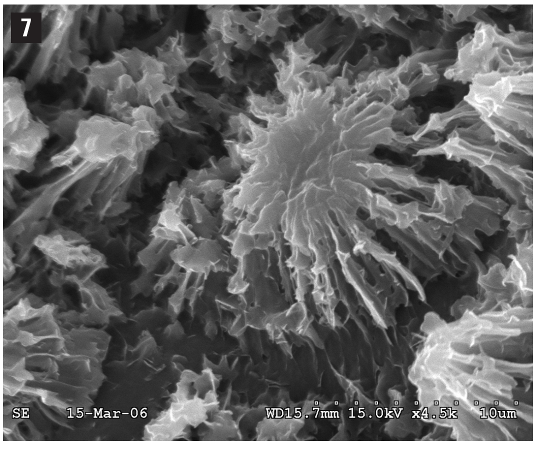

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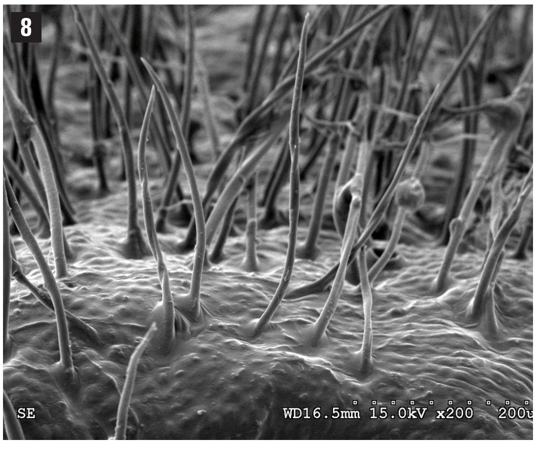


accretion of dozens of preparations, hundreds of examined specimens and many hours of analysis – hence their accuracy and extraordinary informativeness. In all types of identification keys, they work better than photography, which is always only a recording of a single observation.

In the micro world

Documentation in the form of photography, however, is not an inferior but rather a very different form of recording observations. With the right tools, it makes it possible to show a world that sight cannot reach and to document objects on a micro- or nanoscale. These tools are microscopes – especially electron microscopes, which allow objects to be magnified even tens of thousands of times. They offer utterly new possibilities and new methods of learning about and understanding the way organisms function.

Transmission electron microscopes (TEM) make it possible to observe the ultrastructure of cells, allowing indirect inferences to be made about the activity of cells or individual organelles. Observations of the internal structure of cells are made using tissue fragments that are prepared by being cut into ultrathin slices tens of nanometers thick, so that different cell structures interact differently with the electron beam. For this purpose, the slices are "dyed" or stained accordingly. In a certain sense, the microtechnical steps are very similar irrespective of the type of microscope used. The material needs to be fixed, embedded in the appropriate medium, cut into slices of a specified thickness, stained, and observed. In light microscopy, we use a variety of dyes that stain specific substances (e.g. cellulose or lipids) in the sample, so that the light then selectively shows the structures that these substances contain (e.g. cell walls or cuticle). At high magnifications, the cells are almost transparent and colorless. To spot something in them, it is necessary to use selectively-acting dyes. In TEM, in turn, the role of dyes is played by heavy metals (osmium, lead, uranium or gold, for example) which, when absorbed by specific structures in the cell, give them different electron densities. This produces greater contrast between the various elements of the image.

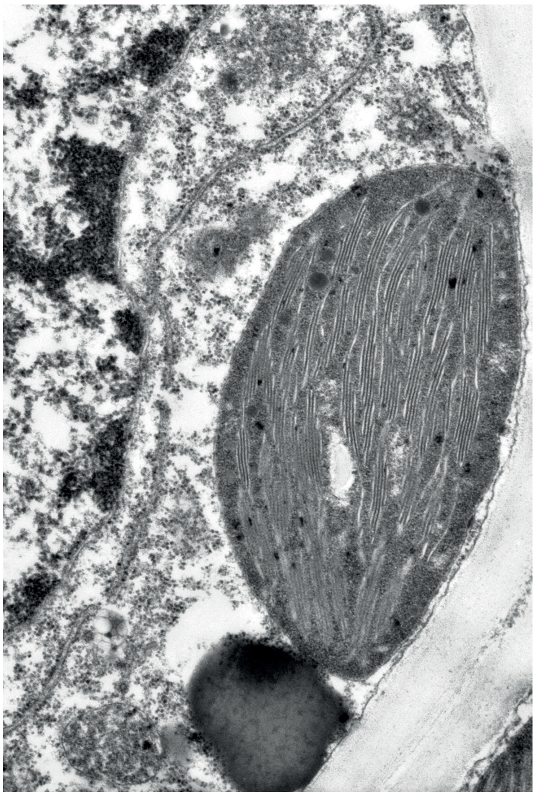
Magnification does not in itself determine the quality of an image. Another extremely important parameter is the resolving power, which determines the size of the smallest details that can be seen in the sample. The resolving power is influenced by the wavelength: the shorter the wavelength, the better the resolving power. The resolving power of an optical microscope is around 100–200 nm, related to the fact that it uses visible light, which has a wavelength in the range 390–780 nm. This resolution is, however, insufficient to observe many smaller biological structures. Electron microscopes use electron beams, and the length

Photo 5
Trichome on a hop leaf (*Humulus lupulus*) – SEM image

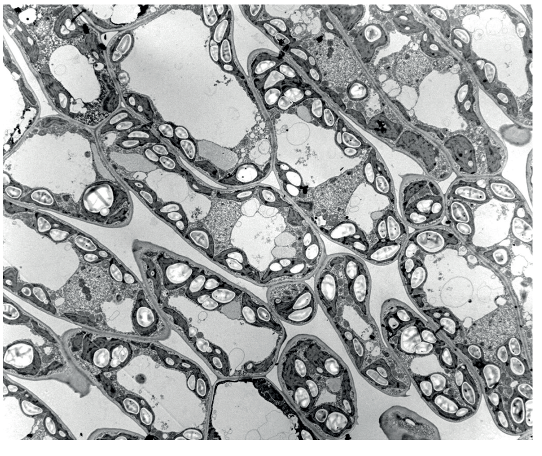
Photo 6
Peltate trichomes on a leaf of silver buffaloberry (*Shepherdia argentea*) – SEM image

Photo 7
Epicuticular wax on a leaf of almond willow (*Salix triandra*) – SEM image

Photo 8
Hairy surface of the fruit of sweetshrub (*Calycanthus*) – SEM image



Cell fragment of collenchyma in a two-year-old Scotch pine needle (*Pinus sylvestris*) – cross-section, TEM image



Cells of palisade mesophyll on the leaf of purple willow (*Salix purpurea*) – cross-section, TEM image

of the beams' waves is several orders of magnitude smaller (approximately 0.1 nm). For an electron beam to interact with a sample, the presence of a certain type of substance is required, hence the heavy metals play a role analogous to that of dyes when an optical microscope is used.

Scanning electron microscopes, on the other hand, use the reflection of the electron beam off the sample, thus making it possible to observe the surface of the object being tested. In the simplest terms, a scanning electron microscope works by directing a beam of electrons at successive points on an object, progressing point-by-point (hence "scanning"), with electrons that are reflected from or knocked out of the object being recorded by the appropriate detectors. The location of the point is combined with the intensity of the received signal to produce an image revealing the topography of the object, which is therefore a representation of its surface. It is quite a distinctive kind of image. Our eyesight is not capable of registering electron waves, just as we cannot see infrared light, for example. It is therefore necessary to translate these waves into information that we can see. The signal is digitally converted into shades of grey. All images obtained with scanning electron microscopes, and also with transmission electron microscopes, are monochromatic, but not because that is their true nature, only because an algorithm is applied that converts the number of electrons captured into a specific value from full black to white. It is worth pointing out here that the color SEM images we sometimes are the work of artists, who choose to add particular colors. These are not real colors, because colors simply do not exist in the biological ultraworld or nanoworld.

Though they produce monochromatic images, electron microscopes are the basic research tools in biology when there is a need to reveal the surface details of small objects. Because they permit observation with a large depth of field, they reproduce surfaces that give the impression of three-dimensionality. This, in turn, means that non-planar surfaces can be investigated without great difficulty, and the catalogue of possible objects to be examined includes a large number of structures, including pollen, trichomes on leaf surfaces, seeds, or even such small structures as wax crystals covering the epidermis. The list of potential applications does not end there. It could be extended, for example, to study the presence of dust contaminants on leaves or the effects of pesticides.

Images in science

All images of this kind can serve as a starting point for scientific analysis and for documenting the features of living organisms, which in some cases are so small that descriptions of them could not be attempted without the use of microscopes. A classic example would be diatoms, which are rewarding to observe using scanning electron microscopy due to the permanence of their shells. The same is true of pollen grains. It is only with the advent of electron microscopy that the extraordinary richness and variety of their structures has been revealed.

Both traditional botanical drawings and electron micrography, therefore, represent invaluable sources of information. The former, however, could not come into being without numerous observations and analyses, while the latter could be likened to evidence presented in court which, when studied, compared and interpreted makes it possible to draw conclusions from experiments or compile detailed descriptions of the structure of objects. ■

Further reading:

Botanical drawings in the Digital Repository of Polish Research Institutes, https://rcin.org.pl/dlibra/collectiondescription/468

What is Botanical Illustration?, https://www.botanicalartandartists.com/what-is-botanical-illustration.html

Rykaczewski M., Ilustration in Scientific Research, Academia 3/2021, DOI: 10.24425/academiaPAS.2021.139785