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BENJAMIN NORBERT EUGÈNE CORENWINDER

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ABSTRACT

Benjamin Corenwinder (1820-1884) was a French scientist and manufacturer, without a formal academic education, who made important contributions to phenomena related to vegetable physiology, the cultivation of beetroot, and the analysis of tropical fruit. He studied in particular plant respiration and the contribution of the different organs of the plant. He found that plants, in their early age, always provided cinders rich in phosphoric acid and after maturity the stems, leaves and roots show no presence of this acid. The events of germination did not consist only in the transformation of starch into sugar; gluten played an important role in the process. Young leaves respired through their nitrogenous part and assimilated carbon with the aid of carbonaceous matters that become organized in their tissues through the intermediate help of chlorophyll. Respiration and assimilation of carbon took place simultaneously but the latter became so attenuated that it could completely mask the effects of the former. Corenwinder carried a detailed study of the growth of beetroot, including the effect of fertilizers, particularly that of sodium nitrate. He also studied a variety of tropical plants, such as banana and chestnut of Brazil..

Keywords: agricultural chemistry, beetroot, respiration, sugars, tropical fruits, vegetable physiology.

RESUMEN

Benjamín Corenwinder (1820-1884) fue un científico e industrial francés, sin educación académica formal, que contribuyó en forma notable al conocimiento de fenómenos relativos a la fisiología vegetal, al cultivo de la betarraga y al análisis de frutas tropicales. Estudió en detalle la respiración vegetal y la contribución de los diferentes órganos de la planta. Demostró que las plantas jóvenes siempre originaban cenizas ricas en ácido fosfórico y que después de alcanzar la madurez sus tallos, hojas, y raíces no contenían este ácido. Los eventos de la germinación no consistían solo en la transformación del almidón en azúcar; el gluten jugaba un rol importante en el proceso. Las hojas jóvenes respiraban a través de sus partes nitrogenadas y asimilaban el carbón con la ayuda de substancias carboníferas que se organizaban en sus tejidos mediante la ayuda de la clorofila. La respiración y la asimilación de carbón ocurrían simultáneamente, pero la asimilación era atenuada en tal grado que podía ocultar totalmente los efectos de la respiración. Corenwinder estudió en detalle el cultivo d la betarraga, incluso el uso de fertilizantes como el nitrato de sodio. También estudió varias plantas tropicales, como la banana y la nuez de Brasil.

Palabras claves: azúcares, betarraga, fisiología vegetal, frutos tropicales, química agrícola, respiración.

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INTRODUCCION

Life and career (Deherain, 1884; Renouard, 1885; Anonymous, 2021)

Benjamin Norbert Eugène Corenwinder was born on June 1, 1820, in Dunkirk, France, the son of Norbert Nicholas Corenwinder, a naval merchant captain, and Anne Marie Hollebeke. After finishing his basic education and acquiring some naval experience he attended the physics and chemistry courses given by Charles Delezenne (1776-1866) and Charles Frédéric Kuhlmann (1803-1881) at the school in Lille. Later Kuhlmann hired him to work in his chemistry laboratory and eventually appointed him his assistant (préparateur). In 1849 he was appointed deputy teacher of the chair of physics and in 1852 full professor at Lille. This academic endeavor ended suddenly when the authorities decided to establish a Faculty of Sciences at Lille, leaving Corenwinder out for lack of a formal academic formation. This incident did not deter him; he now turned his efforts to the sugar industry becoming a manufacturer and looking for applications of chemistry to agriculture. His first paper was related to the preparation of large amounts of pure nitrogen by decomposition of a mixture of potassium nitrite and ammonium chloride (Corenwinder, 1849a). A year later he reported the first preparation of the two crystalline phosphorus chlorides, PI_2, and PI_3 (Corenwinder, 1850b, 1851a) and published his first paper on vegetable physiology (Corenwinder, 1851b). His professional success led to his appointment as director of the laboratory of the large industrial concern, Crespel-Lecreux at Quesnoy-sur-Deûle (1863).

Corenwinder was fully recognized for his research, professional, and public activities. He served as Director of the Agriculture Station of Lille, Deputy Mayor of the city of Lille (1870-1874, 1876-1878), and President of the Committee of the Department of the Nord for the 1878 Universal Exposition. In 1867, towards the Second International Exposition, he was appointed to organize the collective exposition of the agricultural products of the department of the North. In 1872 he was elected general secretary of the Société Industrielle du Nord de la France and in 1878 he founded the Société des Agriculteurs du Nord, eventually becoming its president. He was a member of the Société des Arts et des Sciences de Lille (1840) and it's President (1872); he was corresponding member of the Société Industrielle de Mulhouse (1880), etc. In 1863 the Congrès des Sociétés Savants awarded him a silver medal for his work on agricultural chemistry and in 1867 a gold medal for his work in chemistry and vegetable physiology. Corenwinder was appointed Chevalier of the Légion d'Honneur in 1867 and promoted to Chevalier in 1878.

Corenwinder passed away in Lille, on 1884.

Scientific contribution

Corenwinder wrote about 60 papers and books (i.e. Corenwinder, 1850a, 1851a, 1874b, 1877) on the subjects of inorganic and organic chemistry, agricultural chemistry, vegetable physiology, sugars, tropical fruits, and natural products. As customary for candidates to the Académie, he published a booklet describing the results of his scientific research (Corenwinder 1878); unfortunately, he failed several times in his attempt to become a member of the Académie des Sciences (section rural economy). In addition to the subjects described below he studied the composition of the fluids of individuals affected by cholera (Corenwinder, 1849b, 1850a); analyzed the possible defined combinations between iodine and phosphorus (Corenwinder, 1850b, 1851a), the direct production of hydracids by means of porous bodies (Corenwinder, 1852) and the defined combinations of chlorine and bromine with phosphorus (Corenwinder, 1853a); he developed a method for determining the industrial value of animal carbon (Corenwinder, 1853b); studied the decomposition of water by means of sulfur (Corenwinder, 1861a); the combinations produced by porous bodies

(Corenwinder, 1861b); and performed the analysis of the seaweed *Sargassum bacciferum* (Corenwinder, 1865c); the chestnut of Brasil (*Bertholettia excelsa*) (Corenwinder, 1873); the nut of Bancoul (Corenwinder, 1875b), and parsnip (Corenwinder & Contamine, 1879a) studied the fruits (banana and sweet potato) of several tropical countries (Corenwinder, 1863b, 1864a, 1875a); developed an accurate analytical method for commercial KOH (Corenwinder & Contamine, 1879b); etc.

Phosphorous migration in vegetables

In a previous work Corenwinder had reported the main chemical modifications that took place in the root of the beet during the second period of vegetation (Corenwinder, 1857b). His main finding was that at the time the first leaves were developed, the beetroot had lost part of its sugar to feed the nascent organs. Afterwards, during the growth of the stalks and leaves, the amount of sugar present in the root changed very little but disappeared very rapidly once the seed began to form. He also found that no phosphoric acid (phosphates) was found in the beetroot when the seed began to form. These results led him to study the migration of phosphorus in other vegetables because it was known that phosphorus accompanied the nitrogenous matter in all phases of vegetable life (Corenwinder 1860).

Corenwinder wrote that the best method to get white ashes was to expose the dried plants to a dull red heat and leave them without stirring to avoid their sticking together. The ashes were then treated with an excess of pure HCl, followed by drying to make the silica insoluble. The dry material was then digested with sulfuric acid for 24 hours, followed by filtration and treatment with an excess of alcohol to precipitate the calcium sulfate. The excess alcohol was eliminated by evaporation. A mixture of ammonia and ammonium sulfate then precipitated the phosphoric acid. The precipitate of magnesium ammonium phosphate was considered pure if it had a characteristic crystalline appearance. This procedure assured that the silica remained insoluble and the phosphate was completely solubilized. Corenwinder also detailed the proceeding to follow when the ashes contained iron, adding that Lázare. Garreau (1812-1892) had recently shown that the ashes of the stems and young leaves of buds were rich in phosphoric acid and the ashes of the woody stems, after the seeds had matured, contained very little phosphoric acid (Corenwinder 1860; Garreau, 1860).

According to Corenwinder, the ashes of the young shoots of beet, which sprung from the roots, contained 12.74% of phosphoric acid while those from the roots itself, contained 12.85% of the acid. Young peas were also rich in phosphates; the ashes of young shoots of 6 to 7 cm high contained 27.45% of the acid compared with 4.44% in the ashes of the dried stalks after the peas had reached maturity. Analysis of the ashes of the first two leaves of beans indicated they contained 24.62% of acid, while the stalk beans after seed maturity hardly contained acid. Other experiments indicated that the vegetable matter secreted by plants from their exteriors gave ashes free from phosphoric acid. General knowledge was that the descending sap excreted these matters. Hippolyte Langlois (1819-1884) had reported that the sap contained a remarkable proportion of alkaline or earthy phosphates; these were completely assimilated by the plant, which rejected all matter destitute of nutrition principles useless for its development (Langlois, 1843). It was also known that crushing the pulp of carrots or beetroots, followed by extraction with cold water, yielded the cellular and fibrous tissue combined with the external covering. Burning this fiber produced cinder containing much calcium sulfate and silica and practically no phosphate. Whatever it was, the phosphates were certainly present in the juices and not in the bodies of plants. Removal of the nitrogenous matter from plants resulted also in the removal of the phosphates, which

Corenwinder believed had an existence independent of the organs and circulated in vegetables to produce phenomena of higher order (Corenwinder, 1860).

Corenwinder reached the following conclusions: (1) Plants in their early age always provided cinders rich in phosphoric acid. After maturity of the grains or fruits, the stem and the leaves contained phosphorous in very little amount; when all the grains have achieved complete maturity, the stem, leaves, and roots would ordinarily show no presence of phosphoric acid; (2) in vegetables, phosphoric acid was present as an intimate combination with nitrogenous matter, their dissolution in water or other reagents dissolved simultaneously the phosphates. These could be fixed by coagulating the albuminous substances by immersing the vegetables in boiling water; (3) plant organs that did not contain nitrogen and were unsuitable for food, seemed equally deprived of phosphates. This type of compounds was not present in the ligneous pericarp of fruits such as almonds, hazelnuts, nuts, etc. where the cinder was composed mainly of silica and calcium sulfate; (4) vegetable matter excreted by plants did not contain phosphoric acid. This was true for manna and Arabic gum. All the phosphorous had been absorbed in the nutrition process; (5) milling young plants and the roots of, for example, beet, carrots, turnip, etc. and treating the pulp with a caustic solution, liberated vegetable fibers still containing pectin and encrusted material. This operation removed the proteinic principles together with the phosphoric acid, as shown by the fact that the cinder of cellular tissue or fibers was composed in its larger portion of silica and chalk. Hence, the skeleton of plants did not owe its solidity to phosphates as occurred in higher animals. The dry leaves that accumulated in forests during winter, yielded cinder rich in iron, silica, and calcium sulfate, and were deprived of phosphoric acid; (6) marine plants growing in rocks were very rich in phosphates. Corenwinder was unable to detect the presence of phosphoric acid in the water of the North Sea and in the crust of the generator of ships navigating the ocean and the English Ocean; and (7) the pollen of flowers and the spores of cryptogams contained substantial amounts of phosphoric acid. It was remarkable that the cinder of the seminal liquid of animals was equally rich in phosphates and that the chemical properties of pollen and seminal liquid were almost identical (Corenwinder, 1860).

Germination

Corenwinder wrote that it was known that during germination of grains, particularly of cereals, an organic acid developed that had not been definitely identified; some believed it was acetic acid, others, lactic acid, as Boussingault had written: "It is doubtful that the chemical action during germination is as a simple as presented by Saussure. It is known that during the course of this phenomenon an organic acid is produced that Becquerel considers to be acetic acid, also it is more probable that is lactic acid” (Boussingault, 1844; Corenwinder, 1851b). This uncertainty led Corenwinder to investigate the subject further.

The first stage was to determine if the formation of the acid took place under normal conditions. For this purpose, Corenwinder germinated wheat grains in a garden and noticed that the softened perisperm showed a pronounced acidity when the development of the germ took place in pure sand or in a plate wetted with distilled water. Afterwards, he germinated about one liter of wheat in a box containing pure sand, letting the stems develop up to the time the grain begun to soften. The young stems with their grains were pulled out, crushed in a mortar, and the soluble part separated by washing and filtration. The filtrate consisted of an acid and limpid liquid, which was concentrated to a thick state. Addition of alcohol resulted in the precipitation of an abundant, coherent and elastic mass, presenting all the properties of gluten mixed with a small amount of starch. This meant that the gluten was contained in the soluble part of the germinating grain. The alcoholic extract was separated by filtration and concentrated by boiling to a syrupy state. This acid material was neutralized with sodium carbonate and then dried. Treatment of the solid residue with diluted sulfuric acid was accompanied by a pronounced disengagement of acetic acid, which was easily separated by distillation. This result showed conclusively that acetic acid, an excellent solvent of gluten, was produced during the germination in order to dissolve the gluten and render it appropriate to contribute to the nutrition of the embryo. Corenwinder also noted that the germination process was accompanied by the release of CO_2, which probably was produced during the transformation of part of the starch to acetic acid. This result indicated why contact with air was indispensable for the development of the embryo; oxygen was needed for the formation of acetic acid. In addition, Corenwinder reported that exposing the germinating grains to ammonia vapor not only resulted in the interruption of the process but also on the attack of thee young stems, which dried and died (Corenwinder, 1851b).

Corenwinder concluded that (1) the events of germination did not consist only in the transformation of starch into sugar, but that the gluten that coexisted in the perisperm of the grain also played an important role in this process, and (2) the gluten was not soluble on water only, nature formed acetic acid from a portion of the gluten in other to facilitate this process. The gluten thus became soluble and contributed to the growth of the embryo (Corenwinder, 1851b).

Respiration of plants

Corenwinder studied in detail during 20 years the phenomenon of respiration of plants (Corenwinder, 1856, 1857a, 1858, 1863a, 1864b, 1865a, 1866, 1867ab, 1868, 1874a, 1876); the paper published in 1874 contains a general description of Corenwinder results and is the basis of what follows. Corenwinder wrote that towards the end of the 17th century, scientists studied the respiration of plants using unrefined methods that nevertheless allowed them to make brilliant discoveries, valuable even today (Corenwinder, 1867a). In particular, their experimental arrangement consisted of a glass bell mounted over a glass plate, full of water and containing the leaves of different plants. They observed that when the setup was exposed to sunlight, the leaves became covered with numerous bubbles of an elastic fluid, which accumulated on the top of the bell. Examination of the gas indicated that it was composed almost completely of oxygen (dephlostificated air). The pertinent experiments and results allowed the botanists Jean Senebier (1742-1809) and Jean Ingenhousz (1730-1799) to write the books that made them famous (Senebier, 1872; Ingenhousz, 1780). Ingenhousz believed that this dephlostificated air was no drawn from the leaves but originated from their pores because its volume was larger than the air that could be recovered from boiling water. Senebier believed that the gas originated from the air of the water that flowed in the leaf. He carried on a brilliant experiment where he exposed to sunlight recipients containing leaves of different plants and filled with air saturated with CO_2 (fixed air), saturated with normal air, full with ordinary water, full with distilled water, and full with boiling water. He reported that the leaves submerged in water charged with CO_2 released the largest amount of gas while the leaves submerged in ordinary water produced substantially more bubbles than those submerged in distilled or boiling water. In relative terms, the leaves submerged in boiling water were the ones that furnished the less amount of gas. Hence, Senebier was the first to observe that the presence of CO_2 in water favored the emission of oxygen (although at that time the composition of fixed air was unknown and that it contained dephlostificated air) (Corenwinder, 1867a).

According to Corenwinder, it was known that the soil was an immense reservoir of CO_2 that plants used as a source of the large amount of carbon they needed for their subsistence and development (Corenwinder, 1874a). Fertilizers and other degraded organic materials contained in the soil gave off to the atmosphere a variable amount of CO_2, according to their state of degradation, humidity, and temperature variation (Corenwinder, 1856). The soil was eminently porous and continuously exchanged elements by diffusion with the atmosphere; the continuous oxidation of its organic matter released part of the CO_2. The gas confined in the soil was partially fixed by the water and by the attraction exerted by porous materials on fluids. The roots of plants absorbed part of the aqueous solution and the remainder was dissipated into the atmosphere. At first thought it seemed that this perpetual release of CO_2 could be determined by analyzing the air layer next to the soil, but Jean-Baptiste Boussingault (1802-1887) and B. Lewy had already reported that at any time, this layer contained the same amount of CO_2 as those layers located much higher in the atmosphere (Boussingault and Lewy, 1844). According to Corenwinder, this result was to be expected, the gas released by the earth and fertilizers was a small fraction of the volume of the atmosphere and was rapidly dissipated by the wind. Anyway, part of this CO_2 was certainly absorbed by the leaves of vegetables. When these were located near the ground, they certainly affected the free diffusion of the CO_2 and could thus be assimilated under the direct influence of sunlight (Corenwinder, 1858). For a long time, the functions of the vegetable kingdom were represented as being of an opposite kind to those of animals. These entities grew to continue their species but were also part of the food chain; they rendered animal life possible. Kingdoms were intrinsically connected, plant life produced intermediate principles, which were consumed by animal life, and animal excretions were the natural nutriments required for vegetable life. Plants purified the air breathed by animals and animals contaminated it; these were complementary processes: animal respiration absorbed oxygen and released CO_2; vegetable respiration absorbed CO_2 and released oxygen. These facts together, maintained the composition of the atmosphere more or less constant. It was rational to accept that vegetables located on the surface of the Earth were submerged in an ocean of CO_2, which renewed itself constantly and in larger amounts as the temperature was higher and the soil more humid (conditions that activated the decomposition of fertilizers, natural and or artificial) (Corenwinder, 1856, 1874a).

The French physiologist Claude Bernard (1813-1872) had discovered the formation of sugar in the liver of animals and presented a newer scheme where plants and animals were compared on the basis of their similitudes rather than upon their differences (Bernard, 1846, 1848, 1872). Still, some basic problems of the phenomenon of respiration remained controversial. It was now believed that respiration depended on the action of sunlight and that it took place on the leaves or green parts containing a particular principle known as *chlorophyll*. Afterwards, it has been found that flowers not colored green and even green parts in the dark, absorbed oxygen and exhaled CO_2, as animals did. This discovery led to the assumption that plants had two modes of respiration, one *nocturnal* and the other *diurnal*, the latter being regarded by botanists as the true respiratory process. This duality seemed surprising, how was it possible for a vegetable to survive when one-half of the respiratory process was unable to support a basic physiological process. Corenwinder's experiments showed that nocturnal respiration was actually the true respiration activity. The absorption of CO_2 by chlorophyll was really an assimilation process (digestion), and, as suggested by Bernard, vegetables and animals breathed in the same manner (Corenwinder, 1874a).

According to Corenwinder, buds, young shoots, and growing leaves, *for a certain time,* absorbed oxygen and exhaled CO_2 *in an ostensible way* and without interruption by day or night, except in the spring when the nocturnal temperature was low and the process was scarcely apparent. This function did not manifest itself only in the darkness; light and heat accelerated it. This process was easily demonstrated by putting the tender plants, picked when young, in a glass bell connected to a water vessel full of a concentrated solution of baryta and an aspirator to stream out the air that had been in contact with the plants. Carrying the experiment with a bud of chestnut tree showed, after a very short period of time under the action of sunlight, the formation of a fast growing precipitate of barium carbonate (Corenwinder, 1857a, 1863a).

Corenwinder also demonstrated that leaves colored red, brown, purple, etc., as those of hazel, garden orache, copper beech, and painted nettle, behaved in the same manner as green leaves, they absorbed CO_2 in the presence of sunlight and released it in the dark (Corenwinder, 1863a, 1864b), also, the respiration process was not accompanied by the release of carbon monoxide in any amount (Corenwinder, 1865a).

Another simple experience permitted demonstrating that during this first period of growth the newly born leaves absorbed, day and night, the oxygen of the air. It was enough to put the plant under a glass bell full of ordinary air and connected to a U tube containing aqueous KOH. The exiting gas was found to be composed only of nitrogen. During this experience, oxygen was breathed in and expired partially, according to the age of the buds, as CO_2, which was absorbed by the KOH solution. This result decreased as the leaves grew and apparently ceased when the organs were fully grown. It was clear, then that vegetables in their young age breathed like animals, absorbing oxygen and releasing CO_2 (Corenwinder, 1858, 1866, 1867a, 1874a).

According to Corenwinder, the limit, beyond which plants ceased ostensible to exhale CO_2 during the day, varied much according to the species, some manifesting it a long while (i.e. *Dielytra spectabilis*), others losing the faculty quickly (i.e. beetroot leaves) (Corenwinder, 1874a). At present, it was not possible to explain the reason for this difference; it clearly depended on the external conditions, for example, heat, known to accelerate all the chemical effects of oxygen, the intensity of sunlight that favored the assimilation of CO_2, and, of course, the nature of the vegetable. It was also; a priori, hard to explain why nascent plants breathed like animals, absorbing oxygen and exhaling CO_2 constantly and then, in the adult state, ceased apparently to exhale CO_2. To answer this question Corenwinder proceeded to analyze the leaf contents (water, nitrogenated substances, cinders, and phosphoric acid) of lilac of white flowers and green leaves of maple, during the period April 15 and October 31, 1873. His results indicated that the water content of the leaves diminished as the season advanced, but not in a regular manner, considerable rains occasionally throwing it back and affecting the analysis of the other components. To overcome this inconvenience, Corenwinder also determined the composition of dried leaves. His results indicated that the proportions of nitrogenous and carbonaceous matters varied according to the stage of growth, and also according to the nature of the plants; maple, for example, containing more nitrogenous matter than lilac, and country trees more than town ones (the paper provides detailed tables of the analytical results for leaves of different sizes at different dates) (Corenwinder, 1874a).

Corenwinder main findings were as follows: (1) during the growth of leaves, the relative proportion of nitrogenous matter diminished rapidly. It was at a maximum when they first emerged from the bud and decreased about the beginning of July, when the fruit of the lilac was formed. Afterwards it changed very little, there seemed to be a small increase as the leaves approached maturity, becoming minimum when that period was reached. When the lilac leaves begun falling, their nitrogenous matter amounted to about one-third of the proportion they had in the beginning; in maple it was slightly larger; (2) the carbonaceous matter augmented rapidly from the moment the leaves emerged from the buds until the completion of their growth, which in the lilac was when the flowers were nearly open. After this point, the amount of carbonaceous matter increased slightly up to September. The leaves of maple presented the opposite behavior, the maximum proportion was at the time of the fall when they had lost a notable part of their nitrogenous matter; (3) the quantity of ash increased rapidly up to June and then it was less pronounced. The mature leaves of maple contained more fixed salts than those of lilac; the former were formed of thicker and less numerous fibers than those of lilac, and consequently they were richer in silica and calcium salts; and (4) the cinders of nascent leaves of maple contained more phosphoric acids than those in a later state of growth (Corenwinder, 1874a).

An examination of the numerical analytical results indicated that during the entire growth period the nitrogenous matters were very abundant, probably organized, and endowed with an existence independent of the vegetable cells (Corenwinder, 1874a). Doubtless, they exercised the animal function of respiration, which then was the predominant operation. The CO_2 resulting from this process was only partly retained by the reducing action of the chlorophyll. Consequently, the young plant exposed to light and atmospheric exhaled an excess of CO_2. In the following period the *relative* proportion of nitrogenous matters diminished and the carbonaceous matters increased. The plant then only exhaled a small quantity of CO_2, the rest being almost retained by the chlorophyll, which decomposed it and fixed the carbon. Later on, the CO_2 ceased to appear, being absorbed by the chlorophyll as quickly as it was generated by respiration. The plant entered now the adult period; under the influence of sunlight it inspired abundantly CO_2 from the air and generated oxygen simultaneously. In this stage the respiratory phenomena were completely masked, and could only be revealed by indirect processes (Corenwinder, 1874a).

According to Corenwinder, all the information presented permitted concluding that young leaves exerted simultaneously two physiological functions: (1) they respired through their nitrogenous parts and (2) they assimilated carbon with the aid of carbonaceous matters that became organized in their tissues through the intermediate aid of chlorophyll (Corenwinder, 1874a).

Corenwinder wrote that Boussingault had found that leaves placed in a bell glass containing pure hydrogen mixed with a little CO_2, in a room feebly illuminated, gave out a little oxygen, showing that the assimilation of carbon had not ceased, which it only did in total darkness (Boussingault, 1864, 1865; Corenwinder, 1874a). It was also known that in a similar amount of light leaves in a glass *full of air* released CO_2 in inspiring oxygen. Hence, putting these two facts together, it appeared that the two inherent functions of the plant, respiration and assimilation of carbon, took place simultaneously, but that *the last became so attenuated that it could completely mask the effects of the former*. Corenwinder believed that his theory was supported by the following facts: (1) Mature green leaves of maize put in the same apparatus were found not to expire CO_2 during daytime, and (2) white-tufted leaves found in a variety of maize, which contained no chlorophyll, did not have the faculty of sensibly absorbing CO_2 and exhaling oxygen as the green and purple maize leaves had in sunlight; but they did exhale sensible quantities of CO_2 in daylight. Corenwinder added that in 1782 the botanist Senebier had reported that the red and yellow tufts of the tricolored amaranth presented the same phenomenon: they did not give off oxygen when exposed to the sun, but that the leaves of the red amaranth had this property (Senebier, 1782, Corenwinder, 1874a). In addition, leaves naturally green, but changing to red at the end of their lives, such as those of the Virginian creeper (*Parthenocissus quinquefolia*) completely ceased to absorb CO_2 and exhale oxygen. Faded leaves emitted CO_2, though not as an act of vitality, but of decay. Analyzing some white leaves gathered from maple, and also green ones from the same tree, the former were found to contain in the dry state 17.06% of nitrogenous matter, and the latter only 13.75%. Thus white leaves were proportionately richer in nitrogenous matter than green ones, the latter being the richer in carbonaceous matter (Corenwinder, 1874a).

Corenwinder also contested the theory that claimed that the roots of a plant were able to absorb CO_2 from the soil (Corenwinder, 1867b). Boussingault and Lewy had found that the soil was an enormous reservoir of CO_2 (Boussingault & Lewy, 1852); in one of their experiences they had found that the air confined in a loose and fertile terrain contained about 10% of this gas. This finding had led them to ask the possibility that the roots were able to absorb CO_2, although in a previous work they had proved that the superficial air did not contained more CO_2 than the higher layers. According to Corenwinder, if leaves covered the ground (as for example in a plantation of beets or tobacco), they would absorb part of the gas during its passage into the upper atmosphere (Corenwinder, 1867b). It was known that aspiring a certain of amount of air through a vessel containing baryta water resulted in the absorption of very little CO_2. In nature, the result was different. The leaves, in virtue of their affinity for CO_2, formed a center of attraction that trapped the gas; absorption of a molecule of CO_2 resulted in the formation of a vacuum that attracted more molecules of the same nature (Corenwinder, 1867b).

Cow milk

Corenwinder wrote that the composition of milk varied little, depending on the constitution of the animal, its feeding, etc. Little was known about the particular influence of each of these factors; it was vaguely known that certain foods resulted in a fatty milk, that others imparted it an agreeable taste and colored yellow milk, that roots of carrots and beet led to an abundant secretion, that certain plant essences communicated to milk their particular odor, and that the quality of butter depended on the nature of the feed (Corenwinder, 1855). Within the subject, Corenwinder decided to investigate the variations of the composition of milk during different periods of the gestation. The results of the analysis of a large number of samples indicated that the colostrum (the first milk taken after parturition) had a particular composition characterized by a large amount of albumin and little content of milk and milk sugar (lactose). These particular compositions occurred before calving indicating that the task of the colostrum was not only purging the young animal even after its birth, as suggested in chemistry books (Corenwinder, 1855).

A cow approaching the time of gestation hardly produced milk; attempts of milking it resulted at the most in the collection of a small number of lumps of casein or coagulated albumin, suspended in an acid liquid. Other times it yielded a small volume of liquid, inappropriate for consumption. In this situation, care was taken to relieve the cow by milking it when the udders were swollen and throwing the liquid to the ground. Corenwinder observed that the milk collected at this time had the appearance of colostrum; this fact led him to determine its composition. He received he a sample of milk secreted six days before gestation; it was a thick yellow liquid of relative density 1.047 that he precipitated with acetic acid and lead sub-acetate. Surprisingly, the filtrated liquid was *levogyre* (lactose is dextrogyre). He dried 500 g the residue and treated it with ether, to determine the amount of butter, and then with boiling water to separate the soluble matter from the insoluble one. The solution was treated with acetic acid and lead sub-acetate. The resulting filtrate was found now to be dextrogyre, signaling the amount of sugar contained in the primitive milk. Analysis of the milk indicated that it contained, by weight, 80.400% water, 1.800% butter, 1.020% sugar, 1.280% soluble salts and organic matter, and 15.500% albumin, casein, etc., showing the composition difference with normal milk (87.200% water, 4.000% casein, albumin, and insoluble salts, 4.400 butter, and 4.400% lactose and soluble salts): the milk of a cow about to calve contained less butter and more sugar than normal milk, and it clearly richer in albumin and casein (Corenwinder, 1855).

Corenwinder reasoned that the deviation to the left of polarized light had to be produced by a substance fixed by the precipitation process. He took another sample of the milk of the cow about to calve and found that it was yellow, very thick, and having relative density 1.049-1.049. He then precipitated it at 40^0-$50\ ^0$C with a small amount of acetic acid and a known amount of lead sub-acetate. The filtrate was found to deviate polarized light 10^0 to the left. After heating over a water bath it whitened and precipitated a large amount of albumin. The new filtrate was now found to deviate polarized light 6^0 to the *right*. Hence, the deviation to the left was caused by the albumin coagulable at 100 ^{0}C and non-precipitable by acetic acid and lead sub-acetate. Consequently, analysis of the true amount of lactose by optical means required previous heating of the defecated liquid to 100 ^{0}C. Normal milk did not require this treatment because it hardly contained albumin. Additional analyses indicated the presence of a brown trembling substance, having all the properties of gelatin. Gelatin seemed to be in larger amount in the colostrum than in normal milk and appeared to play an important role in the feeding of the young veal (Corenwinder did not check this point further) (Corenwinder, 1855).

Corenwinder concluded as follows: (1) to obtain reliable results in the optical analysis of milk it is necessary to heat it previously to 100 ^{0}C, in order to coagulate the albumin present in large amount in a period close to parturition; (2) under certain circumstances the optical determination was usually uncertain due to the presence of gelatin that deviates polarized light to the left; and (3) the milk of a cow about to calve tended to become colostrum and contained much albumin and little sugar and fatty matter (Corenwinder, 1855).

Beetroot

Corenwinder wrote many papers on the subject (Corenwinder, 1857b, 1865b, 1870, 1875c, 1883, 1884, 1885; Corenwinder & Contamine, 1878; Condamine & Woussen & Woussen, 1875). In the first one he mentioned that beetroot was a biannual plant and that under natural conditions the stem, flowers and fruit appeared during the second year of vegetation (Corenwinder, 1857b). During the first period the plant accumulated a variable amount of sugar in its root, if it was desired to use it for producing grain, it was picked up in October, kept in silos, and replanted in April in a soil appropriately fertilized were the vegetation was promptly realized. Harvesting of the grains was carried on by the end of August (Corenwinder, 1857b). According to Eugène Melchior Péligot (1811-1890), the sugar content of the roots had decreased to traces when the grains had reached maturity, indicating that the original sugar had been used as food for the organs that developed during the second year (Péligot 1838). Corenwinder decided to investigate this phenomenon further. For this purpose, during the month of November of 1856, he selected 30 beetroots originating from the same seed, which were as much as possible similar (same external form, thickness, etc.), planted them at different periods of the vegetation (April, May, June, July, and August), and then determined their average chemical composition. He found that (1) the juice decreased only very little during the formation of the first leaves and also up to the time that the grains approached maturity; (2) the amount of water increased a little at the time of maturity of the grains; (3) the amount of sugar decreased a little during the formation of the first leaves, which still could not feed from the atmosphere. Afterwards the leaves and stems began grew considerably while the sugar decreased little. The sugar content began slowly decreasing at the time the grains began to appear and then faster until the sugar disappeared at maturity;

(4) the potassium content increased rapidly at the time the grains begun forming, and became five times larger at the completion of vegetation. The potassium was probably in the form of nitrate; (5) the amount of woody material and of cinders substantially increased until the grains were mature, due particularly to potassium and silica; (6) the amount of nitrogen changed very little; and (7) the content of phosphoric acid decreased to zero during the second period of vegetation (Corenwinder, 1857b).

Corenwinder wrote that spite the tremendous economic importance of beetroot it had not been sufficiently investigated scientifically. He had had the opportunity of analyzing the cinders of the residues of the distillation of beetroot molasses and, to his surprise, found that their composition varied widely not only with the variety of the plant but also with their geographical origin. This led him to analyze the cinders of the beetroots themselves (Corenwinder, 1865b). For this purpose, he selected plants grown in the same field, which had not been fertilized, fertilized with animal excrements, vegetable cakes, and guano, and also collected in different French departments (Saint-Omer, Dunkirk, Lille, Nièvre, Aisne, etc.). The soil of Saint-Omer was very humid and spongy; that of Dunkirk was composed of sand and silt, originating from terrain that had been gained from the sea by means of dikes. It was very fertile and capable of yielding abundant crops for 20 to 30 years, without the need of fertilizers. The Lille terrain was made of clay and siliceous clay and had been fertilized for years with human waste of the village; those of Nièvre and Aine were also made of clay and siliceous clay and usually fertilized with farm manure and animal urine.

After a series of analysis of the beet produced in several departments, Corenwinder concluded that the chlorides varied more or less in proportion with the quality of the soil and the fertilizer applied. Beetroots growing in soils fertilized with liquid fertilizers generally contained more chlorides that those fertilized with animal waste or guano. Beetroots from Nièvre and Aisne contained more potassium salts and less sodium salts than those of the departments of the North. This important fact could not be attributed to the manures; manures were more profusely employed in the North than in other regions. It probably depended of the nature of the soil, which was probably richer in potassium in Nièvre and Aisne than in the North. The beets richer in potassium salts were also the sweeter and Corenwinder believed that there was a relation between sugar richness and potassium content in beetroots, but this was still to be proven. The paper included detailed numerical tables of the analytical results (Corenwinder, 1865b).

In another memoir, Corenwinder studied the composition of the mineral matter in beetroot using samples collected in Italy (Modena, Milan, Bologna, and Vicenza) and in Northern French localities (Havrincourt and Haubordin Nord). He presented his results in two tables giving the value of the density of the juice and the amount of sugar, potassium sulfate, potassium chloride, sodium carbonate and phosphate, potassium phosphate, and insoluble salts, contained in one liter of juice (Corenwinder, 1870). The results indicated that the richest beetroots originated from Havrincourt (Pas-the-Calais) while those from Haubourdin (Lille) contained a smaller amount. The latter had been grown in the same terrain, which had been divided into three equal parts, one not being fertilized, another having received a chemical fertilizer, and the third fertilized with peanuts meal. The beetroots from the first lot contained the most sugar. The amount of mineral salts contained in the Italian beetroots was substantially larger (about double) that the amount present in the French samples. The sugar of the beetroots from Bologna was not good enough to produce crystalline sugar; it was appropriate only for the manufacture of molasses. The quantities of chloride present were clearly a function of the nature of the soil in which they were grown; if it was humid and swampy the root absorbed a large amount of sodium chloride. The new results proved that the amount of sweet matter present in the root did not increase by addition of a potassium salt to the soil. The French species were richer in sugar than the Italian ones but poorer in the amount of potassium they contained. Hence, it was doubtful that potassium had the ability of favoring the production of sugar and starch in vegetables. The amount of sodium salts was largest in the juices loaded with chlorides, showing that sodium penetrated the roots in the form of sodium chloride. Corenwinder provided a detailed description of the analytical methods he employed (Corenwinder, 1870).

Corenwinder wrote that the growers in Northern France used to partially defoliate beetroot and use the leaves as cattle food. This operation took place usually in August and September, when the plants were in full vegetation (Corenwinder, 1875c). During the summer months when the dryness decreased the growth of natural and artificial prairies, beetroot leaves were a resource for the farmer that lacked the food appropriate for the animals of the farm. It was assumed that defoliation was advantageous because it allowed airing the roots. The manufacturers of sugar had long realized that defoliation decreased the sweetness of beetroots. According to Corenwinder, the problem had become real due to the deplorable conditions of the native sugar industry; for this reason, he decided study the subject in detail. For this purpose, he selected a field located in Sequedin, district of Lille, which was free of trees, hurdles, and pits, and had been fertilized in winter. He selected a number of beetroots to be defoliated in the standard manner and left another equal number to grow naturally, without defoliation. In due time, he analyzed the roots to determine their sugar content. His results indicated that defoliation had decreased the crop by 14,600 kg of roots per hectare, obviously a serious loss to the farmer. In addition, the analytical results indicated that the defoliated roots contained less sugar and that the disappeared sugar had been replaced by more or less the same weight of water. All these phenomena were easily explained on the basis of the known fact that most of the carbon necessary for the formation of sugar in beets originated from the atmosphere and was captured by the leaves. The defoliated plant dedicated part of the sugar previously formed the creation of new leaves (Corenwinder, 1875c).

Corenwinder and Honoré Woussen (1827-1911) studied the effects of chemical fertilizers on beet particularly that of sodium nitrate, which was heavily used by the growers (Corenwinder & Woussen, 1875). It was known that this fertilizer increased significantly the growth of the plant. Unfortunately, its exaggerated use resulted in the formation of the roots of large size, which made them inappropriate for the manufacture of sugar. The fertilizing effect of sodium nitrate resided in its nitrogen content; hence it was of interest to investigate if this effect could be increased by the addition of complementary substances of standard fertilizers such as the phosphates, which were assimilable by sulfuric acid, and potassium salts. For this purpose, Corenwinder and Woussen selected a piece of land that had been used for many years for the cultivation of beetroot and divided into a number of plots equal to the number of fertilizers they intended to test (eight). These fertilizers were applied on the same day and the beetroot crops collected on the same date. The fertilizer regimes were as follows: (1) no fertilizer; (2) 500 kg of ammonium sulfate plus 200 of potassium chloride and 240 of mineral phosphate; (3) 500 kg of ammonium sulfate plus 240 of potassium sulfate and 240 of mineral phosphate; (4) 600 kg of sodium nitrate; (5) 600 kg of sodium nitrate plus 200 of potassium chloride and 400 of superphosphate; (6) 600 kg of sodium nitrate plus 200 of potassium chloride plus 400 of superphosphate containing 10-11% of soluble phosphoric acid; (7) 400 kg of sodium nitrate plus 200 of potassium nitrate and 400 g of superphosphate; and (8) 400 kg of sodium nitrate plus 400 and rich superphosphate (containing 17% of soluble phosphoric acid). The results indicated clearly that superphosphate produced the most significant effect; it induced a regular vegetation of the plant and increased substantially its sugar content (Corenwinder & Woussen 1875).

Corenwinder and Woussen insisted on the point that when chemists found nitrate in beets it did not mean they had put it in their fields, because other fertilizers, particular ammonium salts and animal matters, nitrified in the soil and formed also nitrates on the roots they cultivated (Corenwinder & Woussen 1875).

Corenwinder and G. Contamine extended the work of Corenwinder on the effects of defoliation on the production of sugar by beetroots (Corenwinder, 1875c; Corenwinder & Contamine, 1878). Now they tried to prove that although the leaves loaded the carbon by a synthesis process yet to be unveiled; it was the root the one that produced the sugar. Corenwinder had also proved that the leaves could absorb the CO_2 present in the atmosphere only under the action of sunlight. Without this absorption the plant ceased to grow.

Corenwinder and Contamine repeated the experiments of Corenwinder and reported that beetroots with large leaves produced 48,740 kg of roots containing 100.20 g of sugar per gram of root and yielding a juice of relative density 1.055 (5.5 ^{0}C), while the corresponding figures for the small leaves resulting from defoliation were 48,230, 8.50, and 1.045 (4.5 ^{0}C), respectively. These results showed once again the important role that the leaves played in the assimilation of carbon. In addition, the roots of beets surmounted by the largest and well-developed leaves were the ones richer in sugar (Corenwinder & Contamine, 1878).

The next memoir described additional experiments regarding the assimilation of carbon by vegetable leaves (Corenwinder, 1883). Corenwinder described the results of new experiments he had done regarding the growth of different plants (tobacco, maize, and beetroot) in pots filled with pure sand, which had been successively washed with diluted HCl, abundant water, and distilled water, to assure that it was totally exempt of organic matter and carbonates. The pots were then watered with a known volume of an aqueous solution of mineral salts (i.e. potassium nitrate, ammonium phosphate, ammonium-magnesium sulfate, potassium chloride, acid calcium phosphate, etc.), deprived of organic substances and carbonates. In this manner the pots were provided with nitrogen in two forms, soluble phosphates, and all the minerals known to be present in the plant. In May 1882 the pots containing beetroots were located in a well-exposed garden, without contact with the soil and watered with distilled water, as needed. For comparison purposes Corenwinder also planted beetroots in a normal field plot, which had been fertilized with farm fertilizers and liquid fertilizers. At due time (July, for example) the plants were pulled out and analyzed. The results with the plants grown in pots indicated that the CO_2 contained in the air was enough to feed the plant of the carbon necessary for elaborating the sugar. After this date, the beetroots grew very rapidly; by the beginning of August the growth of both sets of plants was very similar but by September the plants growing in the soil were clearly progressing more rapidly, showing numerous leaves. By October the plants grown in the pots began losing their leaves rapidly while the ones in soil continued growing vigorously. Corenwinder ended the experiments in November, pulled out the plants, carried their analysis, and concluded as follows: (1) the beetroot grown in the sand deprived of organic matter acquired through its leaves all the carbon necessary for fabricating sugar; (2) the beetroot grown in normal soil seemed to have obtained from the soil the carbon necessary to fulfill this purpose, although it was not certain that this source provided all the carbon; (3) beetroots grown in soils containing a large provision of carbonated matter most probably absorbed from the terrain, by means of its roots, part of the carbon it required. Was it possible that this carbon, by unknown reactions, contributed to the formation of sugar together with the carbon absorbed by the leaves? This was a probable fact but hard to prove based on the present state of knowledge. It was probable that the plant absorbed by its roots the bicarbonate, as well the small amount CO_2 dissolved in water. Anyhow, the amount provided by both sources was necessarily limited. If it was assumed that vegetables assimilated carbon by exercising many different or similar functions, it was necessary to admit, in the present state of physiological knowledge that the existence of none of these functions had been demonstrated (Corenwinder, 1883).

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