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Review

Multipurpose plant species and circular economy: *Corylus avellana* L. as a study case

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Abstract

Corylus avellana L. is one of the most cultivated species in the world. Mainly utilized with the purpose of obtaining food material, hazel trees cannot guarantee constant kernels productions given the threats related to pathogens and to adverse conditions, especially in a globalisation and global changes scenarios. This matter led us to consider the opportunity of using hazel tree in all its parts and for several purposes, due to its multifunctional characteristics. As a pioneer species, it is a precious plant useful for forest restoration purposes and for forest successions/wildlife facilitation. Its roots enter into symbiosis with truffles making this species exploitable for hazelnuts and truffles production. The precious elements contained in what is considered "waste" deriving from hazel crops (i.e., leaves, skins, shells, husks and pruning material), could be reused and valorised in the perspective of a circular economy that is opposed to a linear one. In particular, a list of several phenolic compounds detected in hazelnut shells has been reported in literature to prevent and delay many human diseases due to their antioxidant properties and to free radical scavenging activities, with implications potentially useful even in the fight against COVID-19. All this makes hazel crop by-products interesting to be valorised as a chemical compound source for human health, even more than a biomass fuel or for bio-char applications. The multiple possible uses of the hazel tree would lead to alternative productions than the only nut productions, avoiding significant economic losses, would decrease the cost of disposal of crops residues and would increase the sustainability of agro-ecosystems by reducing, among other things, the production of wastes and of greenhouse gases deriving from the usual burning of residues which often happens directly in fields.

Keywords: *Corylus avellana* L.; Sustainability; Circular economy; Multipurpose plant; Forest restoration

1. Introduction

Last century has been featured by an economical growth model called "linear economy" [1]. This has facilitated the use of products in a disposable way, creating a greater anthropic impact (i.e., much more waste, garbage and pollution, together with an increasingly use of energy and raw materials and soil uses change). This model is based just on the raw materials extraction, on mass production and consumption, and on the waste disposal once the end of the product life is (too early) reached, as if resources and space were infinite options and they could be used and thrown away indefinitely/infinitely. The resulting endless extraction and disposal flow is inefficient and expensive, and it represents one of the main causes of terrestrial and marine pollution, greenhouse gas emissions and, consequently, climate change [2].

The unsustainability of the described model was widely demonstrated by Georgescu-Roegen [3]; alternatively, he suggested a Bioeconomy model, based on the principles of thermodynamics [3,4]. Nevertheless, Georgescu-Roegen model failed in affirming itself even though it represented the Costanza and Dary Ecological Economy premise [5,6].

In more recent years there, have been various attempts to introduce criteria of greater sustainability related to economic processes [7]. In order to reach this goal, architects, physicians, and economists began searching for and developing a new and more sustainable economic model based on a more responsible way of producing and consuming: the model proposed is the so-called green economy which should be used in addition to blue economy and mauve economy [8]. In all cases, an attempt is there to move to a circular model. In opposition to the linear one, this model is based on a product's life cycle extension and on a consumption waste valorization in which wastes, representing a problem for disposal, would become a reusable resource. Indeed, the circular economy model is basically an economical system thought to regenerate on its own, and in which wastes are reduced, re-used, and recycled [9].

The Ellen MacArthur Foundation, one of the most active realities for the promotion of the model, estimated that this kind of model can generate 1800-billion-euros economic benefit by 2030 [10]. Besides, the use of alternative strategies to avoid additional losses and produce several high value-added chemicals could minimize the volume of non-renewable materials used today, enough to greatly reduce greenhouse gas emissions and dependencies on non-sustainable resources. Considering their available volume (practically low cost) locally and globally, associated with a rich, functional, structural, and chemical heterogeneity, all agro-industrial wastes should be considered for this purpose as well [11]. In this context, an integral (whole) utilization of plants and the use of multipurpose plant species are of great importance.

This article is about the hazel (*Corylus avellana* L.), a key species that includes both the valorisation of wastes and the multifunctional aspect. Its great diffusion worldwide (see chapter 4), combined with the peculiarities above all related to the fact that it produces dry fruits, makes it a very precious resource both from a quantitative point of view and in relation to the several high-quality by-products obtainable. We took Italy as main example and as a case study for several reasons: it has a thousand-year historical use and cultivation of hazelnuts, it is considered the Nation that produces the highest quality nuts, it is the second largest producer of hazelnuts in the world, it has a wide Local Traditional cultural links with the Hazel and, finally, Italy is one of the country in the world with the most important industries that utilizes hazelnuts, from the production to the final processing.

2. The multipurpose plant species

In modern agriculture, what very often happens in relation to the production process is the predilection of determined and pre-fixed parts of plants which generally offer a single and faster product to be sold. This reflects the increasingly widespread consumerist trend also in cultivation, through an increasingly impactful and standardized agriculture, based on extensive, intensive, mechanized and industrialized criteria. Derives from it a lack of optimal utilization and valorisation of plants in their entirety, causing more waste and a greater consumption of resources, and precluding the multifunctionality interests of crops. More in detail, in most cases, only the fruits or seeds of the plants cultivated for food purposes are used, while the rest (i.e., leaves, stem, branches, etc.) are considered as waste. To reduce these "wastes", different options were proposed, referred for example to the production of yarns by exploiting *Citrus* fruits residues [12], the extraction of resveratrol and other active compounds from grape skins and seeds [13], the production of autoadhesive, biocompatible, and pain-free hydrogel polymeric films from onions' non-edible outside layers extracts [14], and the possibility of using *Moringa oleifera* leaves extracts to develop bioadhesives with biocompatible polymeric microparticles used for exuding wounds treatments [15].

Regardless of how orchard/crop wastes are managed, an increase in production proportionally corresponds to an increase in wastes. In the agro-industrial context, according to specific esteems, around 140 billion tons of biomass generated every year in the world result from the agricultural sector, and a considerable part is recognized as waste not conflicting with food availability, e.g., leaves, roots, stalks, bark, bagasse, straw residues, seeds, shells, husks, and wood [11]. Some agricultural crop residues, such as shells, husks, pruning wood, etc., are traditionally burned in the fields causing or accentuating some environmental problems (i.e., soil erosion/instability, decrease of the soil/topsoil biological activity, air pollution [16,174], and increasing accidental wildfires risk), even if sometimes they can be useful as fertilizers or to disinfect the soil. Other times, crops residues are used as economic fuel with low calorific value, but also with risks for human health [17–23]. Apart from a negative impact on the environment and on human health, waste disposal implies a not to be underestimated overall economic cost [24].

By expanding the circular economy concept to agricultural systems and environmental restoration, particular attention must be paid to the multipurpose plant species. In this context, hazel plant is an example of multipurpose plant, as it is a woody species cultivated to obtain direct food products (fruits), which have not undergone a process of absolute domestication and which are also found in the wild [25–30]. Therefore, they are species of plants which can be conveniently used for reforestation or for orchards purposes. In the case of forest restoration, they could provide an additional income, deriving from fruit harvesting. In case of orchards, if they were to lose economic interest, the same trees could be left to grow spontaneously, promoting the processes of forest biological succession. Multipurpose plant species, according to their own prerogative, can be used in many fields and for different purposes. Multipurpose woody species could provide the typical agronomic/arboriculture functions, they could provide silviculture functions by wood and other typical products from forests [31], while, at the same time in their biological/ecology role, they could provide forest or agro eco-services. It would be smart to exploit such high potential to prevent environmental damages and negative economic implications.

The European and Mediterranean territories' characteristics allow an optimal growth of several plant species, which easily adapt to the various soil and climatic conditions. All of them can be used as multipurpose plants, to prevent hydrogeological instability, for beekeeping purposes (i.e., propolis, pollen, monospecific/wildflower honeys, and honeydew honeys), or for edible mushrooms (sometimes truffles as well) proliferation, in a direct (symbiotic species) or indirect (favouring/accompanying species) way. Wood of those species can be used as timber or the resulting biomass (wood, pruning residues, leaves, seeds, husks, shells, etc.) can be used for biofuel pur-

Table 1. Multifunctional characteristics of tree species.

Tree species	Common uses	Potential uses
Prunus avium L.	Fruits	High quality timber and veneer operations [32], monospecific honey [33].
Malus x *domestica* Borkh.	Fruits	High quality timber [34], veneer operations [32] and monospecific honey [33].
Pinus pinea L.	Seeds	Land restoration [34], green shelter and succession facilitation (biogroups) [35], niche for edible fungal species (incl. truffles) [36], propolis productions [37], preservation of traditional landscape and ornamental plants.
Prunus dulcis (Mill.) D.A.Webb	Seeds	Preservation of traditional agricultural landscapes [38], alternative to *Olea europaea* trees in colder climates*.
Castanea sativa Mill.	Seeds	Niche for edible fungal species [39] and monospecific honey [33]; preservation of traditional agricultural landscape.
Ceratonia siliqua L.	Fruits/seeds	Preservation of traditional agricultural landscape and ornamental plant [40], fodder (pods pulp), fluid biofuel, food purposes i.e., sugar and molasses, dry fruits, pods pulp, fruit, or seed meal (e.g., additive E410) [41].
Pyrus communis L.	Fruits	High-quality timber [31].
Olea europaea L.	Fruits/seeds	High quality timber [42], oil and fluid biofuel, preservation of traditional agricultural landscape [43], tourism [44], prevention against agro-pastoral deforestation and related wildfires [45].

*Schirone personal observation.

poses. Between them, there are plenty of woody species of agro-forestry interest, which stand out for their multi-functional characteristics, as shown in Table 1 (Ref. [32–42,42,44,45]).

3. *Corylus avellana* L.

Corylus genus belongs to the Betulaceae family. It is widespread throughout the northern hemisphere, including 18 known species. Between them, *C. avellana* L is a plant having appeared during the Tertiary period, particularly during the Oligocene, between 33 and 23 million years ago [46]. Its differentiation began during the Miocene period, counting two distinct types of hazel trees: one with narrow leaves (*Corylus insignis* Herr) and the other one with large leaves (*Corylus mac-quarry* Herr), which can be considered the ancestor of *C. avellana* L. [46]. Native to Asia Minor, *Corylus avellana* L. spontaneously grows in a very wide territory, ranging from Portugal to the Ural Mountains in the east, and passing through the Italian and Balkan peninsulas, Caucasus, and Kazakhstan [47,48]. To the north it goes up to 68° latitude along the Norwegian coasts, while in the south it is found until Lebanon and Syria [49].

C. avellana primarily spreads during the Quaternary age, in the so-called "hazel age" [50], consisting in a period characterized by a relatively hot-dry climate (Boreal or Anatermic climate), between 6800 and 5500 B.C. Subsequently, the anthropic factor also played an important role in the diffusion of this species, as described for example for Apennine mountain chain, where *Juglans* and *Castanea* species appearance specifically marked the beginning of a significant human influence, hastening the disappearance of *Pinus* species and bringing about a more recent re-expansion of *Quercus* species, *Fraxinus ornus* L. and *Corylus avellana* L., which represent the main components of today's thermophilus bushland [51–53]. This vegetation dynamic principles could be extended to other European countries [54–57].

Corylus avellana L. is characterized by a shrubby and polycormic growth form. Sprouts originate from the portion situated between the hypogeal and epigeal part of the plant (collar or colletto). It is a short-living shrub, which reaches 3–4 (7) meters of height; the deciduous leaves are simple and alternating, rounded-shaped with a double-serrate margin. *C. avellana* is a monoicous plant. Male unripe inflorescences (catkins) are visible since summer, and their flowering is completed between January and March, when their development is completed, and pollen grains are ready to be distributed (mostly by wind). The female flowering process is shorter, taking place between January and March [58,59]. Hazelnuts are appreciated as fodder by wildlife (mostly forest birds and large and micromammals), and the male inflorescences (catkins) represent an appreciated fodder as well during winter/early spring, especially by squirrels (*Sciurus vulgaris*, Linnaeus 1758) (Cianfaglione, personal observation). The fruit (hazelnut) is a globular-ovoid achene composed of a woody pericarp containing the kernel, an edible nut containing a high percentage of oil [60]. The fruit is entirely or almost entirely covered by the fruit integument (husk), which is composed of two pubescent deciduous and frayed bracts, light green in color and brownish in time [59] (Fig. 1).

Fig. 1. The hazel pant and its principal parts. (A) The whole plant. (B) Leaves. (C) Catkins. (D) Female flowers. (E) Hazelnuts with husks. (F) Fruits and Kernels. (G) Hazelnuts, shells, and kernels with skin. (H) Kernels without skin.

Corylus avellana L. is a typical mesophilic species that can face short periods of dryness during the vegetative period. It prefers medium-textured soils (especially the volcanic ones), but it also adapts to any kind of soil (even stony and steep ones). It grows naturally on territories ranging from 200 to 1700 meters above sea level and it can be considered a heliophilous species even though it tolerates shade conditions, and it resists cold and wind [59]. The species can be found in rich and mesophilic pedological contexts, such as valley floors, planitial and riparian environments (i.e., *Fraxinus excelsior*, *F. angustifolia*, *Carpinus betulus*, *Ulmus, Populus, Acer*, *Salix, Alnus* species, and *Quercus robur* forests), and in slopes as well, in fresh contexts characterized by the presence of *Quercus cerris, Q. petraea, Fraxiunus ornus*, *Pinus nigra* s.l., *P. sylvestris, Fagus sylvatica, Populus tremula, Betula* species, *Castanea sativa* and *Ostrya carpinifolia* forests), even in more thermophilic *Picea abies, Abies alba, Larix decidua* formation, or in the most fresh or mesic conditions in *Quercus pubescens* and others thermophilic (broadleaved, conifers or mixed) formations.

In oceanic conditions, the species can be found on seacoasts, even within the dunal/retrodunal vegetation (in more or less primary formations). In mesophilic (or in shady) condition it can be found on seacoast formations even in Mediterranean conditions (i.e., mixed with *Laurus nobilis*). In mountains, under continental or Mediterranean conditions, in lesser sunny expositions, the species can also be found on thin and poor soils (i.e., cliffs and dejection fans; where mosses develop well), in more or less primary conditions.

Corylus avellana L. can often be found mixed with *Sambucus, Prunus* species or other shrubs generally belonging to the *Prunetalia spinosae* phytosociological order [61]. In relation to forest vegetation dynamics, *C. avellana* L. is a pioneer/opportunistic species, which often could not appear immediately among the first woody species in the vegetation succession. Within the same environmental conditions, its presence tends to be more sporadic in undisturbed conditions and very much frequent (even dominant) in more disturbed conditions. It is frequently found in disturbed places (clearings, mantles, margins, and pre-forest conditions), after natural or artificial disturbances (i.e., after agricultural abandonment, after forest harvesting, in hedges of not excessively intensive cultivated areas). For example, *Corylo avellanae - Populion tremulae* [62,63] represent a phytosociological alliance of arborescent pioneer vegetation in mesotrophic forest contexts (i.e., woody shrub vegetation that may appear on previously disturbed surfaces, on soils that has remained uncultivated for some years, in hedgerows, roadsides, forest clearings/pre-forest formations, field margins, and unmanaged secondary grasslands). *Corylus avellana* can be common and widespread in disturbed woody formations, subject to wood harvesting (clear cutting to coppicing), as for example it happens for *Carpino betuli-Coryletum avellanae* [64] plant-associations, that remain stable as long as the perturbation persists. *C. avellana* represents a typical species in the constitution of many woody formations of the *Querco roboris-Fagetea sylvaticae* [62] phytosociological class. In forests context, *C. avellana* could take part even in mature natural forests but it tends to be a more sporadic presence.

All the *Corylus* species produce edible nuts, but only those of *C. avellana* L. possess the greatest morpho-organoleptic characteristics and consequently the highest agricultural, food, and economical value. In relation to

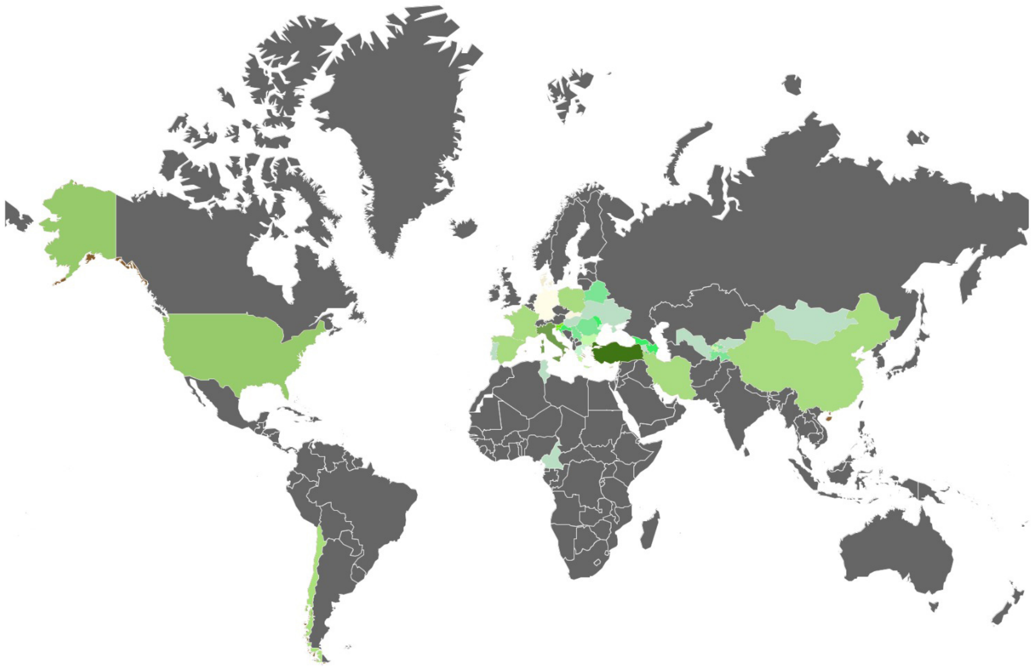

Fig. 2. Map of the main world countries where hazel trees are cultivated. The map was created by using the data shown in Table 3. In dark green the countries in which hazel is most cultivated are represented, and in lighter green those in which hazel is cultivated lesser.

Table 2. Hazel harvested areas expressed in hectares (ha) related to the main world countries, from 2010 to 2019.

Country	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Turkey	432439	429955	422675	422501	423261	434119	705445	706667	728381	734409
Italy	55904	70492	57992	71459	72125	72214	69285	72772	78590	79350
Azerbaijan	22691	23242	23768	24822	25207	27322	31814	35782	39021	43381
USA	11736	11534	11736	12141	12141	13759	14973	16190	17810	20230
Chile	4199	7544	8687	8712	8686	8712	13109	13110	13104	24437
China	10645	11000	11500	11500	11900	12410	12892	13211	13521	13824
Georgia	15739	17065	13731	22127	18689	19461	16421	11931	9493	13422
Iran	19133	16610	13614	20416	20631	31041	18419	17822	18144	18472
Spain	13803	14067	13912	13800	13591	13301	13137	12806	13510	13020

The table was created by using Faostat data, available on www.fao.org/faostat [70].

these gastronomic and economic interests, *C. avellana* is the most representative and commercial species of hazel. *Corylus avellana* is used to improve the quality characteristics of the seeds (nuts) of similar species (i.e., *Corylus maxima*, *C. colurna*, *C. americana,* and *C. heterophylla*) [65,66]. Hybrids of *C. avellana* and *C. americana* are very interesting because they aim to combine the larger and quality nuts deriving from the old-world species with the disease resistance deriving from the American species [67].

Most ancient domestication evidences of *C. avellana* has been carried out in ancient times by Turkic people, but also in Italy there are very ancient archaeological evidences and very old documents attesting the first modern hazel crop (52). Currently Turkey represents the most important world hazelnuts producer [68] followed by Italy, Azerbaijan, USA, Chile, China, Georgia, Iran, and Spain [69,70] (Table 2, Ref. [70] and Fig. 2).

4. *Corylus avellana* L. in Italy

In the Italian territory, *C. avellana* is naturally spread over all the national regions where it grows on plains, hills, valley floors, and in the phytoclimatic *Fagus sylvatica* belt [61]. Generally, the hazel tree develops as a shrub even of large dimensions. In exceptional cases, it becomes monumental in size like a veteran tree, albeit always polycormic. At least in Italy, it was not possible to find known wild hazel trees reported as veteran trees of monumental interest. According to the Mipaaf (Italian ministry for agriculture and forestry policies) list of Italian veteran trees [71], the hazel is considered to be of monumental interest starting from a single stem circumference of 200 cm at 1.30 m. These dimensions could be more easily and quickly reached from cultivated, monocormic species (i.e., *C. colurna*) or monocormic-forced plants (cultivated samples). For example, only one *Corylus colurna* could be found in the Italian national database of monumental trees, placed in Emilia-Romagna region, under cultivation conditions. Therefore, in our opinion, especially in case of wild hazel plants (polycormic, not pruned, and not in crop conditions), the limits should be reconsidered to almost one stem reaching one meter in circumference. For instance, Valzo di Valle Castellana (Central Italy) forest hosts a wild hazel tree of monumental interest. The forest was bought to be saved from further harvesting and, consequently, that wild hazel tree is supposed to never be cut down [72]. It is characterized by some stems, and few of them exceed 1m in circumference, while the overall height is of 6 m and the total crown is of 5 m [72]. In Italy, hazel plants are traditionally cultivated throughout the country and wild hazel grows in every region. Historically, the cultivation of hazel is mainly linked to three regions: Campania (South Italy), Lazio (Central Italy), and Piemonte (North Italy). Often, one province contributes to almost the totality of the entire regional production as it is the case of Viterbo province (in Lazio region) and Cuneo province (in Piemonte region). In Campania region, on the contrary, hazelnut productions are spread quite equally between Napoli, Caserta, Salerno, and Avellino provinces. If the genus *Corylus* takes its name because of husks looks like a helmet, which in classical Greek is called "córys", or because of the word "kurl" (the celtic name for hazel tree); the specific name *avellana* takes his origin from the province of Avellino, The specific name could eventually derive from the genitive form of the town of Abella (now, Avella), always in the Province of Avellino, because this province area it was considered a particularly suitable area for the cultivation of hazelnuts already during the Ancient Roman Empire. Albeit with some variations, this specific name was known and commonly used by Latin writers to refer to the hazel and its nuts as for example, Cato (in Head VIII of De re rustica) and Pliny the Elder's Encyclopedia (Naturalis Historia, book XV). This name was selected by Linnaeus [73] from Leonhart Fuchs's "De historia stirpium commentarii insignes" [74], where the species was described from oldest Latin authors [75].

Sicilia (South Italy) is the fourth Italian producing region. Its productions have been remarkably increasing in recent years, even though the yields do not reach the other Italian regions' quantities (Fig. 3).

Fig. 3. Map of the main Italian regions where hazel trees are cultivated. The map was created by using a dark green for regions in which hazel is highly cultivated and a lighter green for regions in which it is cultivated lesser.

Coming to percentages and varieties, 40% of Italian hazelnuts are produced in Campania, which is considered the most ancient cultivation site in Italy [58]. The mainly cultivated varieties are "Mortarella" (38%) and "San Giovanni" (37%) for industrial elaboration, "Tonda Giffoni", "Tonda Bianca", "Tonda Rossa", "Campanica", and "Riccia di Talanico" for direct food uses [76]. Lazio region contributes to about 33% of the national hazelnut production, of which about 96% is in Viterbo province [76]. In particular, the "Monti Cimini" area, that is characterized by flat soils which are often irrigated, represents one of the main Italian areas of production [77]. The hazel variety mainly cultivated in Lazio region is "Tonda Gentile Romana" (85%), followed by "Nocchione" (10%, which also acts as a pollinator of other varieties) and "Tonda di Giffoni" (5%) [76]. The remaining 27% of the national hazelnut production is divided between Piemonte and Sicilia regions. Appreciated for its organoleptic characteristics both by the confectionery industry and for fresh consumption, the mainly cultivated variety in Piemonte (over 90%) is "Tonda Gentile delle Langhe" [76]. Finally, in Sicilia region, the mainly cultivated varieties are "Siciliana", "Ghirara", "Minnulara" and "Lancinante" [76].

5. The hazelnut

Hazel is one of the most important crops in the world. *C. avellana* L. is mainly cultivated with the purpose of obtaining hazelnut kernels that are more and more requested and commercialized all over the world as edible nut [70].

In the past, traditionally this species was often home-grown in hedges or margins. A very common home-orchard/hedge use (self-consumption) of hazel was to eat fresh hazelnut kernels, unripe or ripe, but not dried. Compared to the dried ones, fresh nuts' kernel taste is very much different, and nuts contain much more water. When eaten at this condition, they were popular as a snack, especially for children and they were appreciated as a snack by mountaineers and shepherds as well (Cianfaglione personal observations, mainly based on unpublished data from L'Aquila Province, Italy).

Nowadays hazelnuts are eaten raw (dry), often roasted or, more frequently, processed by the food industry and transformed into chocolate, cakes, biscuits, etc. The famous traditional Italian chocolate "Gianduia" is attributed to the Turin confectioners, who mixed part of the cocoa with hazelnut to create this type of chocolate. Many versions and variations have been created by various brands, until today, after more than 215 years of documented history of this chocolate. One of the most important confectionery industries in the world, the Italian Ferrero company, has set all its production on the use of hazelnut chocolate under the trademarks of Ferrero and Kinder. Its bestseller, Nutella, is nothing more than a hazelnut chocolate cream (a variation of the "Gianduia" chocolate motive). This type of chocolate motif or in any case hazelnuts, are an important part of the products of many other major Italian brands (i.e., Caffarel, Loacker, Perugina, Elah Dufour Novi, Nurzia, Condorelli, Sperlari, Pernigotti and many others).

Hazelnuts are characterized by several nutraceutical properties [78–83], which make them a useful food for health and valuable from a nutritional point of view. Hazelnut kernels, as an example, are rich in essential amino acids, dietary fibres, vitamins, minerals, and unsaturated fatty acids, which play a key preventive role from many diseases [84]. Lipids are the main nutrient contained in the hazelnut kernel. They constitute over 60% of the kernel dry weight. Among fatty acids, specifically, oleic acid is the predominant one reaching up to 82.8%, followed by linoleic, palmitic, stearic, and vaccenic acids [85–88]. A high content in monounsaturated fatty acids makes hazelnut oil very much similar to olive oil, mainly contributing to reducing the risk of coronary heart diseases. The adulteration of olive oil with hazelnut kernel oil, in fact, is becoming a more and more common procedure, and quite difficult to detect due to the very similar chemical profile of the oils. Even though hazelnut oil does not constitute a health risk as it happens with low quality oils used for adulterations, this matter represents a serious problem both for olive oil producers and consumers [89,90]. Used to dress salads, for cooking, and for food preparation because of its unique flavour, hazelnut oil has a great potential in the pharmaceutical industry. Besides fatty acids, in fact, tocopherols and tocotrienols contained contribute to the prevention of cardiovascular and neurodegenerative diseases. Phytosterols can induce significant reductions in low-density lipoprotein cholesterol levels, phenols can play a key role in cancers prevention, and dietary fibres contained can prevent and mitigate cardiovascular diseases and colon cancer [88]. Hazelnut oil composition makes it extremely suitable for cosmetic uses as well. Specifically, phospholipids and vitamin E contained in virgin hazelnut oil are directly associated with a skin moisturizing effect [91]. Besides, considering that the hazelnut oil yield was found to be approximately of 1000 Kg/ha (around two times that of soybeans) and thanks to a high thermo oxidative stability conferred by the

Table 3. Hazelnut with shell production (tons) in the main producing countries over the world, from 2010 to 2019.

Country	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Turkey	600000	430000	660000	549000	450000	646000	420000	675000	515000	776046
Italy	90270	128940	85232	112650	75456	101643	120572	131281	132700	98530
Azerbaijan	29454	32922	29624	31202	30039	32260	34271	45530	52067	53793
USA	25401	34927	35500	40823	32659	28123	39916	29030	46270	39920
Chile	2400	5200	6300	9500	11500	8750	14250	16800	20330	35000
China	19500	22000	23000	23000	23621	25101	26312	27314	28316	29318
Georgia	28800	31100	24700	39700	33800	35300	29500	21400	17000	24000
Iran	18443	18758	19532	20655	10098	13516	16465	15835	15978	16121
Spain	15086	17590	14406	15300	13542	11423	9510	10487	8030	12370

The table was created by using Faostat data, available on www.fao.org/faostat [70].

high percentage of unsaturated fatty acids contained, hazelnut oil is a potential source for oleochemical uses as well, and, as such, it could easily be used in place of petroleum which is not inexhaustible and whose price is constantly growing [92]. Moreover, after being roasted, "Tonda Gentile delle Langhe" kernels can originate a hydroalcoholic infusion which, once distilled and enriched with different aromas, lead to the production of a hard alcoholic drink called "Frangelico". The liqueur, produced in the Italian Piemonte region, dates back to more than 300 years to hermit monks living there [93]. There are plenty of traditional hazelnut-based liqueurs existing in Italy, sometimes known nationally and internationally, but more often only locally. The rich and intense flavour of Piedmonts' hazelnuts, as an example, makes them suitable for the production of a liqueur, the so-called "nocciolino", which involves the infusion of fruits in an alcoholic solution, and the addition of sugar syrup to sweeten.

In 2019, hazelnuts worldwide production amounted to around 1.20 million tons [70]. According to consumers' food preferences and to the previous year's trend, hazelnut production is expected to grow progressively over the next coming years in most of the major producing countries. Strongly contributing to the high worldwide production, in Turkey, which is the leading hazelnut producing country in the world, in 2019, for example, there have been produced 776046 tons of hazelnut. Italy is only second to Turkey with a production which, in 2019, amounted to 98530 tons and a harvested area (almost 80000 ha in 2019) which is constantly increasing over the years. Azerbaijan is the next best producer (53793), followed by the USA (39920), Chile (35000), China (29318), Georgia (24000), Iran (16121) and Spain (12370) [70]. Table 3 (Ref. [70]) shows a general increase in hazelnut with shell production over the years, in the main producing countries over the world. Few exceptions regarding a lower production trend are mainly due to adverse weather conditions and/or pathologies from which plants have been affected.

Italy represents not only the second worldwide and the first European hazelnut country producer but also, together with other countries as for example Chile, USA, Azerbaijan, and Georgia, over the years it has been seeing an increase in the rates of hazelnut exports, contrary to what is happening in Turkey. The first importing country from Italy is Germany, followed by France, Belgium, Poland, Switzerland, and Spain. In terms of volumes, the Turkish hazelnuts sales far exceed the Italian ones, but the quality of Italian hazelnuts is more appreciated and appropriately remunerated by the European importers [94]. Nevertheless, the high quality of Italian hazelnuts is threatened by pathogens, in particular those which are directly dangerous for nuts. Recently, for example, Italian hazel cultivations have been strongly attacked by various species of bedbugs, such as *Gonocerus acuteangulatus* Goeze (1778), which is the most common, significantly compromising the production of hazelnuts. This bedbug is responsible for the abortion and for the decay ("cimiciato") of hazelnuts and it can also be a vector of the fungus *Nematospora coryli* Kurtzman, causing the hazelnut stigmatomycosis [95,96]. Both of them cause a bitter/rotten taste to the hazelnut kernels, making them inedible and unprofitable for the food industry sector [97]. These pest problems could be fostered by mundialization, due to the arrival of new pests/vectors [98,99] and by global changes, due to climate change impact stresses. Because of pests and climate change threats, the increasing uncertainty in guaranteeing a constant production of high-quality hazelnuts could represent a good reason to upgrade care, and consequently the use of chemicals and of maintenance operations (increasing economic and environmental costs). However, at the same time, a regular production uncertainty could represent an excellent incentive for crop product/management diversification, thinking more of a use of the whole plant, so that producers could better compensate for economic losses [11]. The big amount of hazelnuts produced in Italy per year corresponds to an even bigger amount of wastes resulting from the hazelnuts harvest. Hazelnut kernels, in fact, represent less than 50% of the total nut weight, while substantial quantities of by-products, as shells, skins, husks and leaves, are produced during harvesting and processing. Among them, the shells account for the majority of this waste, representing between 50 and 60% of the total hazelnut weight [100]. Assuming that the weight of hazelnut shells is equal to an average of 55% of the total fruits weight, if the annual production of hazelnuts in shell is known, the quantity of deriving shells is easy to estimate. Considering 2019, the Italian production of around 98530 tons of in shell hazelnuts corresponds to 54191.5 tons of shells. Generally, waste disposal represents a not to be underestimated overall cost and, specifically, it has a negative impact on the environment [101], especially if not managed properly.

6. Uses of the hazel tree

If we exclude hazelnuts and its derivatives, the possible uses of the whole hazel plant or its portions are potentially several as follows.

6.1 Whole plant

Given the growing demand for hazelnuts on the market, the tendency is to increasingly extend hazel trees' crops, and, in that case, they could be considered one of the main causes of environmental problems concerning land consumption [102–104]. For instance, such land consumption can be reflected in soil use changes (i.e., destruction of the mosaic of traditional landscapes, where pastures, woodlands, shrublands, and various traditional crops are replaced by extensive hazelnut plantations), and eroding also the land portions now left to the secondary succession; landscape degradation (i.e., anthropization, pollution, landscape homogenisation/simplification, loss or danger to traditional varieties and agronomic biodiversity); drought and water availability problems (i.e., drying out of water bodies, sinking of aquifers, contamination of drinking water basins and aquatic ecosystems changes), and others human impacts [105].

On the contrary, an adequate land planning based on more environmental and landscape attention and proper policies could foster the hazel trees' contribution to environment amelioration and to reforestation issues (including forest quality enhancement and the increase of forest ecoservices), justifying their planting in place of other species or in association with them. The characteristic of being a pioneer species makes the hazel tree a precious plant for forest restoration works. There is not a vast literature on the subject, but the species is indicated by some naturalistic engineering manuals as particularly suitable for the consolidation of unstable slopes [106–109]. More in detail, Bischetti *et al*. [110], based on a comparative survey on different species of conifers and broad-leaved trees, report *C. avellana* as the most resistant to shear forces exerted by landslides. Its shrubby habit suggests its use to solve specific problems as well. For example, during a project commissioned by Terna (Operator of the Italian high voltage transmission grid company), the SIRF – Società Italiana Restauro Forestale (Italian Forests Restoration Society) proposed its use to consolidate the soil of power lines' corridors below electric cables [111]. This was proposed in order to reduce the soil erosion with a woody species that can act as a good compromise: on the one hand to guarantee a minimum continuity of the "forest" cover, and on the other hand to limit maintenance costs for the electricity company which otherwise could more often be obliged to cut or top trees under power lines. In addition, hazel plants could provide fodder for wildlife and several products/services for landowners.

Hazel trees are also used as symbiont for truffles [112–114] (i.e., *Tuber melanosporum* and *T. aestivum*) [115]; consequently, the cultivation of truffles is another aspect that can be associated with hazelnut crops. Generally, the first results in synergic cultivations (truffle + hazelnuts) are observed in the fifth or sixth year after planting, sporadically in the third year [116], but the market demand is in strong expansion and suggests the development of a "dual purpose" hazelnut cultivation (hazelnuts and truffles) with prospects of excellent economic results. Specialized nurseries exist to produce hazel trees mycorrhized with truffles, with the possibility of choosing between the hazel varieties (i.e., Gentile delle Langhe, Tonda Romana, and Tonda di Giffoni) and truffle. New generation nurseries that produce truffle mycorrhized plants are technologically advanced nurseries that can also offer the customer assistance and specific cultivation manuals [117]. Of particular interest are the small gardens managed at a family-level system, using mycorrhized plants with the possibility of collecting hazelnuts and truffles to make ends meet.

The hazel plant has a considerable ornamental value in summer and in winter (during the flowering period). For this purpose, *Corylus* species are often cultivated in public and private gardens as well as along some avenues. Over time, numerous varieties distinguished by their habit or the color of their foliage have been selected. It is worth mentioning some of these varieties: *C. avellana* var. *contorta* Bean., characterized by very twisted stems and branches, var. *pendula* Dipp., with weeping branches, var. *aurea* Kirchn. and the other yellow or yellowish foliage forms (i.e., "anny's purple dream", "merveille de bollwiller", "webb's prize cob") as well, var. *fusco-rubra* Dipp. and the others with purple, red or pink foliage (i.e., "red majestic", "rode zellernoot", "red dragon" and "burgundy lace") which also feature deeply engraved leaves. *Corylus avellana* 'Heterophylla' is a decorative form characterized by leaves with a very fringed margin [118–120].

6.2 By-products

One of the most interesting aspects of the hazel tree as a multipurpose plant lies in the possibility of practically using all the by-products deriving from the fruits' processes, as well as other parts which are generally considered wastes or devoid of economic value. In addition extracts of European hazelnuts were detected to exhibit stronger antioxidant activity then kernels [121–124]. In some cases, the processes for using these materials are already technologically mature, while in others the transition from experimentations to the industrial phase has not yet taken place.

6.2.1 Shells

Hazelnut shells represent approximately 50% of the total hazelnut weight and thus leading to an important amount of wastes around the world [125]. The chemical characterization of hazelnut shells postulates them as lignocellulosic material composed of cellulose 15.4%, hemicellulose 22.4%, lignin 25.9%, proteins 8%, ashes 5% and extractives 24.6% [126]. Their chemical composition, the good stability, a low ashes content, a porous structure, and a great adsorption capacity, make hazelnut shells (as well as other nutshells) extremely useful to prepare activated carbons, and to be used as an effective CO_2 adsorbent, much cheaper if compared to the most commercial activated carbons [127]. Besides, in particular because of their hemicellulosic component, hazelnut shells represent potential precursors of specific prebiotics (xylooligosaccharides and arabino-xylooligosaccharides) which are very beneficial for human health [125].

In relation to the extractives (24.6%), phenolic compounds are the most referred group deriving from lignocellulosic biomass [125]. So far and before hazelnut shells, their best use was burning them as boiler fuel [128]. Nevertheless, in the last few years, some studies were performed to evaluate the potential valorisation of hazelnut shells as sources of important biomolecules as natural antioxidants with important properties for packaging [129], food and pharmaceutical industry.

Recent literature cites new valuable substances extractable from the shells, with particular attention to phenolic compounds. Their antioxidant, antiallergenic and antimicrobial effects on human bodies which may trigger several pathological conditions and/or age-related chronic diseases [130–133], together with an increasing interest and predilection of natural antioxidant compounds over the synthetic ones, is leading the cosmetic, pharmaceutical, and food and construction industries [134–136] to increase their research and development of new products containing such natural substances [137]. Regarding the construction sector, as an example, because of their lignocellulosic composition, hazelnut shells could be used to produce lower cost rigid polyurethane foams, commonly used as lightweight thermal insulating construction materials [138]. Moreover, hazelnut shells' flour deriving from the food industry can easily be used, in percentages of 30–40, for biobased thermoplastic composites' compositions, due to their mechanical properties and because of their full biodegradability [129]. In Table 4 the phenolic compounds detected in hazelnut shells are summarized [139–141].

A wide range of phytochemicals and phenolic compounds, possessing substantial antioxidant and radical scavenging activities, anticarcinogenic [142–144], antimutagenic [145], and antiproliferative effects [146], are present in plant-derived products. These compounds are potentially useful for a wide range of human health applications. For example, quercetin, known for its activity against cancer prevention, chronic inflammation, and cardiovascular diseases [147], has been recently studied for its potential activity against SARS-CoV-2 replication [148]. Different factors affect the composition of phenolic extracts and the antioxidant activity: parts of kernel (shell, skin, green leafy covers, flowers, and leaves) [139], extraction methods (use of ultrasound, microwave and CO_2 supercritical) [149–151], and antioxidant assay used [139]. Phenolic compounds have been reported to prevent and delay many pathologies and this is due to their direct and indirect antioxidant properties, and to their free radical scavenging activity [139]. The biologically active molecules give electrons or hydrogen atoms to reactive free radicals preventing lipid oxidation or cellular damage and act as natural antioxidants with many health benefits [133,139]. The potential antiviral activity of hazelnuts may be related to the presence of quercetin, a flavonol found in fruits and vegetables. Quercetin is a molecule deeply studied in recent times due to its potential activity against SARS-CoV-2 replication [148].

6.2.2 Shells as biomass for energy production

Agricultural residues, hazelnut shells included, are often burned in fields making soils less fertile and increasing air pollution [152] or used as raw material for furfural productions [123]. Guney [153] states that, if the goal is to promote the sustainability of agro-ecosystems, in the perspective of a circular economy, the conversion of (agricultural) biomass to energy, also called bioenergy, represents an excellent opportunity. Hebda *et al.* [154] confirm that the lignocellulosic composition of hazelnut shells, to illustrate, makes them suitable as a raw material for biofuels productions. Specifically, Sullivan *et al.* [155] assert that from 1 ton of hazelnut shells, around 5500 K/cal of energy is produced. The same authors report that in Turkey, for instance, hazelnut shells are used in homes, restaurants, and bakeries for cooking. Rukavina *et al.* [156] describe Italy as the EU's most active residential market for the biomass sector, in terms of a high number of installed biomass stoves. They assert that fossil fuelled devices are being frequently replaced in order to be powered by renewable energy sources, such as wood biomass, pellet, and, also, nutshells. Between them, hazelnut shells' homogeneous particle size and low ashes production makes them very similar to pellet composition [156]. Due to their chemical composition, hazelnut shells, through a proper gasification technique, could be easily converted into hydrogen gas [157–160], to be used, for instance, as a fuel for electric systems [161].

Table 4. Phenolic compounds detected in hazelnut hard shells.

Phenolic compounds	More abundant components
Phenolic acids	gallic acid, vanillic acid, methyl gallate, veratric acid, galloylquinic acid, coumaroyl, quinic acid, feruloylquinic acid, protocatechuic acid.
Flavonoids	quercetin, myricetin, quercetin 3-rhamnoside, myricetin 3-rhamnoside, rutin, taxifolin, naringin, catechin, epicatechin, epigallocatechin.
Tannins	four isomers of B-type procyanidin.
Diaryleptanoids	giffonin V, giffonin P, carpinontriol B.
Lignans	ficusal, celignan, erythro-(7S,8R)-guaiacylglycerol-β-O-4′dihydroconiferyl alcohol, erythro-(7S,8R)-guaiacylglycerol-β-coniferyl aldehyde ether, erythro-(7R,8S)-guaiacylglycerol-β-O4′-dihydroconiferyl alcohol, dihydrodehydrodiconiferyl alcohol, balanophonin.

6.2.3 Skins

Hazelnut skins are the brown perisperm, which cover hazelnut kernels, under the shell. Between wastes produced during the hazelnut industry, skins are considered the main by-product, accounting for around 2.5% of the total nut weight [162]. Hazelnut skins are obtained after roasting processes which can lead to different by-products qualities, according to both the extraction solvents and protocols used, and to the roasting degree; specifically, it was proven that high roasted hazelnut skins extracts possess higher antioxidant activity compared to low-roasted ones [163].

Analyses made on hazelnut skins' chemical composition showed they are very rich in dietary fibers (67,7%) and exphenolic compounds (233 mg GAE/g); besides that, Özdemir *et al.* [164] have ascertained that the oil fraction contains a high amount of tocopherols (2.77 μg/g) and oleic acid (75.2%). Furthermore, Ivanović *et al.* [162] indicate that the total phenolics content and the corresponding antioxidant activity is higher in hazelnut skins, compared to natural and roasted kernels. More specifically, the monomeric and oligomeric flavan-3-ols represents the main polyphenolic subclass, accounting for over 95% of the total polyphenols content. Hazelnut skins' total antioxidant capacity (TAC) is remarkable as well, ranging between 0.6 and 2.2 mol of reduced iron/Kg of sample, and being around 3 times the whole walnut TAC, 7–8 times that of dark chocolate, about 10 times that of espresso coffee, and around 25 times that of blackberries [165–167].

Beside the multiple hazelnut skins' utilizations deriving from high phenolics contents, the dietary fibres contained make them useful for pathologies associated with body weight control, for example high cholesterol, and for promoting the *in vitro* fermentation growth of *Lactobacillus plantarum* P17630 and *Lactobacillus crispatus* P17631, which exert a strong prebiotic like effect [168]. Furthermore, extracts of hazelnut roasted skins could significantly decrease the proliferation of a human colon cancer cell line [88].

Finally, the hazelnut skin was evaluated as a source of nutrients for dairy cows [169], while the production of fibrous structure from hazelnut skin was evaluated as an ingredient in cake as model bakery product [170]. The powder of defatted hazelnut skin may be used as natural brown colouring agent [164].

6.2.4 Husks

Hazelnut husks are the green bracts (fruit integument) which surround hazelnut shells (fruits). They represent a significant agricultural residue, counting around 120000 tons of waste per year worldwide. A study carried out by Akgul [152] shows that their structure is mainly composed of carbon (about 40%), oxygen (45%), ash (5–8%), hydrogen (5%), and nitrogen (1%). The corresponding chemical structure is composed of around 35% of cellulose, 20% of hemicellulose, and 35% of lignin.

In the past, husks were used as a popular herbal tea, or macerate in alcohol to obtain a liquor called "nocchietto", "vellanino", or "nocciolino". Husks are characterized by a very strong and acid taste (the basal part is thicker, juicy, and fleshy, in opposition to the more apical part which is drier and memebranaceous) (Cianfaglione personal observations, mainly based on unpublished data from L'Aquila Province, Italy).

Nowadays, hazelnut husks are considered mainly as waste, but they can be a valuable source of polyphenols [171]. Furthermore, their possible utilizations are for the most part related to biofuels production. Guney [153] asserts that, because of the high lignin content, hazelnut husks, once their components are separated and the moisture is removed, can be converted into industrial material, biofuels, biogas, and heat.

The depletion of fossil fuels (and their harmful consequences on the environment) together with forests wood production decline, as an example, makes it necessary to turn to alternative and renewable energy sources. According to Guney [153], pelletizing, for instance, offers consumers a good opportunity to make agricultural biomasses easy to handle and transport, also considering that hazelnut husks' heating value is around 18.35 MJ/Kg.

The high lignin quantity contained in hazelnut husks makes them usable for the construction sector as well; Zieleniewska *et al.* [172] has ascertained that, compared to certain types of insulating materials such as polystyrene foam or mineral wool, for instance, the use of husks to produce natural fillers and obtain rigid polyurethane foam composites reduces costs significantly. More specifically, Copur *et al.* [173] indicate that adding up to 20% of hazelnut husks in medium density panels production does not imply a regression of characteristics if compared to the standard materials.

6.2.5 Leaves

Leaves represent a high quantity of by-product deriving from hazel tree cultivations. Copur [174] affirms that, once fallen, most of the times, together with other pruning residues as branches, they are burned in fields contributing to the atmospheric pollution and to the increase of greenhouse gases. Largely consumed as infusion, hazel leaves are traditionally used in folk medicine for haemorrhoids, varicose veins, and oedema thanks to their astringency, vaso-protective and anti-oedema properties [175].

Ramalhosa *et al.* [140] indicate that, similarly to hazelnut kernels', skins', husks', and shells' composition, hazel leaves contain several phenolic compounds; specifically, leaves were found to contain 3-caffeoylquinic acid, 4-caffeoylquinic acid, 5-caffeoylquinic acid, caffeoyltartaric acid, *p*coumaroyltartaric acid, myricetin 3-rhamnoside, quercetin 3-rhamnoside, and kaempferol 3rhamnoside, in addition to gallic acid, caffeic acid, *p*-coumaric acid, ferulic acid, and sinapinic acid which have already been detected.

Besides a high hazel leaves' antioxidant activity with similar behaviour of all cultivars analysed, a study carried out by Oliveira *et al.* [175] revealed gram positive and negative bacteria to be very sensitive to hazel leaves' extract. Eventually, Sullivan [155] asserts that, in a production system that involves the recirculation and enhancement of nutrients, hazel leaves (and husks) could be used both as bedding for animals and as excellent organic fertilizer when mixed with animals' urine and feces.

6.2.6 Prunings

Each year cultivated plants need to be pruned to remove the frequent huge collar sprouts' production. Starting from 5–7 years of age [116], the cultivated hazel plants are even pruned (the branches) in order to organize the production of hazelnuts. The resulting material (i.e., branches, leaves, sprouts…) can be used in various ways.

Sullivan [155] asserts that hazel wood, which represents the greatest amount of pruning biomass, is light brown, straight grained, durable, and very hard. Enescu *et al.* [49] reports that, traditionally, it has been used in rural crafts, including baskets and panniers, hurdles for fencing, barrel hoops, and wattle in "wattle and daub" plasterwork. The use of hazel trees to make sticks is also well known. The characteristics of hardness and elasticity of the wood make it particularly suitable both to produce walking and fighting sticks [176]; in Italy, the stems of hazel plants (wild or cultivated) were used to make mountain sticks and shepherd's sticks. The poet Gabriele d'Annunzio in one of his poems ("I pastori", *Alcyone*, Milano, Treves ed., 1903) speaking about the shepherds going from mountains to the seacoast pastures in Abruzzo, recited as follows: "*Rinnovato hanno verga d'avellano*…" (they have renewed a stick made by hazel tree...). In the past, according to traditional knowledge, sticks were often made from hazel plants, not only for the peculiar technical characteristics of the wood (i.e., elasticity, lightness, softness to be easily worked, and resistant enough), and for its wide availability. In addition, there were some popular beliefs that consider hazel tree sticks to have the capacity of driving away snakes, and branches were used by wizards to summon dead people or by dowsers to locate the presence of water (Cianfaglione, personal observations from Italy, France, Poland, Germany, Czech Republic and Romania) [177].

Since a few years, hazel wood has been re-evaluated, even as fuel. Specifically, a high lignin content makes it suitable for thermo-chemical processes. In a study carried out in Italy, Monarca *et al.* [178] discovered that the highest quantity of hazel pruning biomass is obtained from 21 to 30 years old plants, and that the high percentage of carbon contained (compared to hydrogen and nitrogen), which makes it similar to hazelnut shells, increases their energy value.

Proto *et al.* [179] assert that the gasification process, for instance, is used to obtain a mixture of gases called "syngas" for heating and power production purposes. According to Abenavoli *et al.* [180], syngas can result from biochar, which is another precious by-product exploitable from hazel pruning material. Obtained from the pyrolysis of different types of biomass, biochar is an organic material, which can be used both as a source of energy and as an organic soil fertilizer [181]. The usage of biochar in the agricultural sector prevents the crop residues burning, and it represents a valid substitute of ashes [182]. Despite the positive role that biochar appears to have on soil fertility [183], attention must be paid in its use, because in some cases negative effects on soil and agricultural productivity are possible [184].

Although, in terms of sustainability, burning crops residues is not beneficial, the farmers' reasons related to this kind of processing could be not neglected, as it could be justified when referring to economic reasons, and soil high clay content or pathogens control. Small fires, very much limited both in space and time, held by non-commercial producers and related to traditional cultivation practices, cannot be compared to the effects caused by the frequent fires deriving from extensive/intensive productions (in terms of intensity, negative consequences, ethics, and risks), nor to the effects caused by burning plants proliferation, including biomass power plants. In Table 5 (Ref. [49,106–120,126–129,133,134,136,137,139,140,

Table 5. Possible uses of the hazel plant and its by-products.

Part of the plant	Product	Reference
Whole plant	Soil protection	[106–111]
	Truffles	[112–117]
	Ornamental value	[118–120]
Shells	Activated carbon	[126]
	Probiotics	[127]
	Packaging	[128,129]
	Cosmetic, pharmaceutical and food products	[133,134,140,142,143]
	Thermal insulating material	[137]
	Biomass for energy production	[154,155,157]
Skins	Roasted skin extracts	[136,139]
	Phenolic compounds	[162,164,166]
Husks	Biofuels and biogas	[153]
	Insulating material	[172]
	Medium density panels	[173]
Leaves	Astringent, vaso-protective and anti-oedema infusions used in folk medicine; Antioxidant and antimicrobial extracts	[175]
	Phenolic compounds	[140]
	Organic fertilizer	[155]
Prunings	Rural crafts	[49]
	Fighting and walking sticks	[176,177]
	Biochar and syngas	[178–183]

142,143,153–155,157,162,164,166,172,173,175–183]) all the possible uses of the hazel plant and its by-products are shown.

7. The hazel plant and its allergies

It is not possible to talk about the hazel, without mentioning the allergies correlated to the plant and its fruits. In fact, both the pollen and fruits may cause allergic reactions that can be, in certain situations, severe.

The most frequent allergies are consequence of hazelnuts and their derivates (cream, biscuits, snacks, etc.), second, after peanut, causing severe allergic reactions in school-age children (6–12 years) and in preschool children (2–6 years) [185]. Hazelnut's allergy is essentially an IgE mediated allergy, it occurs because the immune system reacts abnormally to the proteins present in this food, producing many IgE antibodies that circulate in the blood. Its manifestations range from oral allergy syndrome, urticaria-angioedema, to generalized allergic reactions and anaphylaxis. The oral allergy syndrome is characterized by itching or burning of the tongue and oral mucosa immediately after eating the food. The urticaria angioedema syndrome is the combination of urticaria with angioedema. Urticaria is characterized by the appearance of pomphi, small edematous, and itchy skin lesions, surrounded by a halo of erythema. Angioedema is characterized by swelling, which may affect the face (lips, eyes, etc.), limbs, or other parts of the body, caused by edema of the dermis. In the most severe cases, those related to generalized reactions and anaphylaxis, the allergic reaction may be evidenced by symptoms of the respiratory system (rhinitis and/or asthma), of the gastrointestinal system (abdominal pain, vomiting, or diarrhea), and the cardiovascular system (tachycardia, hypotension, shock). The potentially dangerous allergens present in hazelnuts are protein substances identified by the following abbreviations: Cor a 1, Cor a 8, Cor a 9, Cor a 14.

• Cor a 1: is a protein that degrades with heat; therefore, those who are allergic can consume roasted nuts without problems. On the contrary, those who consume the raw fruit can have localized reactions, for instance, hives and itching, but without the risk of a systemic shock.

• Cor a 8: is definitely more insidious. This allergen is a protein that remains stable in the fruits even after being heated and it can be transmitted to other food. It may not trigger a serious localized reaction but can cause serious symptoms such as an asthma attack or a laryngospasm, or vomiting and diarrhoea.

• Cor a 9 and Cor a 14: are stable proteins (which do not degrade to heat and digestion) that, as allergens, can give very serious reactions, especially in children. Children with IgE antibodies directed against nut proteins react rapidly, within minutes or hours, when exposed to these foods [186]. Recently, a new protein called oleosin, which causes allergies especially in children has been discovered in hazelnuts. Researchers isolated it from the oily fraction of the fruit and showed that, for some children, this was the only allergen responsible for their allergic symptoms [187]. This is an important discovery because it will help easily diagnose hazelnut allergy in patients who are negative to currently available allergy tests, which do not allow identifying allergies to oleosin.

In the spring months, many individuals show allergic reactions to hazel pollen that in that period plants release into the air in large quantities. Pollen allergens are various protein or glycoprotein molecules able to cause the typical symptoms of cold, such as rhinitis and conjunctivitis, and are often associated with oral allergy syndrome. One of the main sources of sensitization is given by profilins, proteins that, however, are denatured by heat and gastric digestion so that the induced allergic reaction is expressed at the level of the respiratory tract [188].

In addition to the allergic reaction produced by the ingestion of hazelnuts and derivatives, or by pollen, attention should be paid to the so-called cross allergies. Cross-allergies are allergic reactions triggered in the same individual by seemingly unrelated causes. They are caused by pollen and foods of plant origin. 70% of people allergic to pollen suffer from cross-reactions with food. Indeed, cross-allergies are caused by similar proteins included in the pollen and vegetal origin food. Behind this, there is an immune response to similar proteins. As an example, Birch pollen allergy and hazelnut allergy is one of the most common cross allergies. Our immune system is not able to distinguish these very similar allergenic molecules but only recognizes them as a risk factor. Thus a cross-allergy is created: a similar immune response to similar proteins.

It is important to note that subjects that suffer a serious allergy to hazelnuts, with possible anaphylactic shock, shall not consume even small quantities of this fruit. Because its traces are frequently present in many confectioned products, allergic people should always check the ingredient list of the product, where it is written if it is possible to find traces of nuts, to avoid the risk of allergic reactions [185].

Finally, it should be underlined that hazelnut allergies are always caused by ingestion or inhalation of protein molecules. All compounds described in this article, which can be extracted from shells and other hazel processing wastes, are of glucosidic or phenolic nature, not proteinic. In addition, they are proposed to be used primarily externally (e.g., cosmetics). Therefore they cannot cause allergic reactions.

8. Conclusions

In traditional farming, crops were partly associated with forestry and small livestock purposes. There was no waste to be disposed of because all the by-products were somehow re-used. What was not reusable was recycled as fertilizer and nutriments were returned to the soil. Instead, the actual trend is often that of looking to obtain one main product from crops, and one main function from plants. In the agri-food chain context, the modern crop system is hyperspecialized (extensive monoculture) resulting in wasteful and far from applying more durable/sustainable processes. On the other hand, modern circular economies aim at using/reusing the crop products and residues as much as possible, processing wastes to increase the crop economical sustainability (value), and promoting, at the same time, a better environmental durability/sustainability of crop processes. The cultivation of hazelnut represents a typical example of an agroforestry system, which could be largely sustainable, representing an excellent case study. Indeed, the worldwide increase in hazel cultivations has caused a significant increase in waste production that requires the development of strategies and technologies to convert crop wastes into new functional products for farming operations, or useful for the market. Currently, these wastes are entirely channelled as fuel material, but as discussed in this review, they can find other outlets, even more fruitful.

Obtaining biomass fuel from agricultural waste products is certainly considerably more ethical and more beneficial for the environment, as opposed to when we consider these as waste to be disposed of. This, not only in relation to the atmospheric human impact reduction, to be cost effective for farmers and local communities; it could be useful even to save trees and forests that are increasingly harvested to be used as biomass fuel.

Regarding biofuels, the most advantageous use of hazel plants' by-products is that of obtaining bioethanol (ethanol) from husks, because alcohol is one of the less pollutant carburants concerning direct health hazards. Similarly, an interesting utilization of shell charcoal (biochar) is in relation to activated carbons preparation, mainly for human health purposes. Recently, the demand for natural compounds, in fact, is increasing and Phenolic compounds are very important in terms of their properties for human health solutions. Hazel crop waste products' characteristics could be used as a solution to decrease human impacts (i.e., thermic insulation material, forest restoration, land renaturation, landscaping for biodiversity and wildlife…). Unlike lignin and cellulose, which are obtained from hazelnut shells and other hazel crops by-products (used for biofuels/bio-char purposes), phenolic compounds possess a certain higher value since they can be used for pharmaceutical, cosmetic, and nutraceutical purposes.

It is important to consider these points with a long-term vision to foster new development strategies (looking to the future), and to foster the ecological economic transition (looking to the present), focusing on an ever-greater application (valorisation) of waste products in favour of human health (products and services), and diminishing the human footprint. Agronomic, forestry, economic, and health policies should look more deeply into these details and opportunities. *Corylus avellana* L., as a multifunctional crop, is precious in relation to the multiple functions and obtainable products, promoting more sustainable costs (greater money savings/earnings). Its dual aptitude (agricultural and forestry) makes this species exploitable not only in the agronomic systems in order to achieve food products, but also, in case of crop abandonment, in forest systems, fostering biological successions thanks to its pioneer behaviour, and facilitating biodiversity (i.e., wildlife, truffles, and other mushrooms).

Integrating solutions with a multipurpose use approach is important, because they can ensure a higher economic sustainability in agriculture and a more durable crop activity for those who are cultivating and processing hazelnuts, eliminating/reducing the problem of the high amount of waste to be disposed by taking advantage of an effective application of the principles of circular economy and a corresponding great environmental benefit. Therefore, the effectiveness of the "green" use of the hazel crop waste as raw material to obtain compounds for different processes introduces a new production chain, which leads to important encouraging economic and environmental consequences at the local and national scale, and especially for hazel growers.

Corylus avellana L., as well as other multipurpose plants, represents a wealth of possible wide resources. Exploiting these plants' uses and new possibilities means to look for new agricultural and environmental opportunities, both for an economical and for an environmental reward.

Author contributions

AA, BS, KC and ADM designed the paper. All the authors equally participated in the manuscript writing, discussions and improvements. KC coordinated the team and directed the activities of this paper. All the authors read and approved the final version of the manuscript.

Ethics approval and consent to participate

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Conflict of interest

The authors declare no conflict of interest. KC is serving as one of the Editorial Board members of this journal. We declare that KC had no involvement in the peer review of this article and has no access to information regarding its peer review. Full responsibility for the editorial process for this article was delegated to MI.

References

[1] Sariatli F. Linear economy versus circular economy: a comparative and analyzer study for optimization of economy for sustainability. Visegrad Journal on Bioeconomy and Sustainable Development. 2017; 6: 31–34.
[2] Turner A. Black plastics: linear and circular economies, hazardous additives and marine pollution. Environment International. 2018; 117: 308–318.
[3] Georgescu-Roegen N. Bioeconomia. Bollati Boringhieri: Torino. 2003. (In Italian)
[4] Mayumi K, Georgescu-Roegen N. An admirable epistemologist. Structural Change and Economic Dynamics. 1995; 6: 261–265.
[5] Costanza R, Daly HE. Towards an ecological economics. Ecological Modelling. 1987; 38: 1–7.
[6] Costanza R. What is ecological economics? Ecological Economics. 1989; 1: 1–7.
[7] European Commission, Directorate-General for Research and Innovation. Innovating for sustainable growth: a bioeconomy for Europe, Publications Office. 2012
[8] Rustomjee C. Financing the blue economy in small states. CIGI Policy Brief. 2016; 78.
[9] Hamam M, Chinnici G, Di Vita G, Pappalardo G, Pecorino B, Maesano G, *et al*. Circular economy models in agro-food systems: a review. Sustainability. 2021; 13: 3453.
[10] Ellen MacArthur Foundation. Towards the Circular Economy Vol. 1: an economic and business rationale for an accelerated transition. 2013.
[11] Zuin VG, Ramin LZ. Green and sustainable separation of natural products from agro-industrial waste: challenges, potentialities, and perspectives on emerging approaches. Topics in Current Chemistry (Cham). 2018; 376: 3.
[12] Sachidhanandham A. Textiles from orange peel waste. Science and Technology Development Journal. 2020; 23: 508–516.
[13] Pezet R, Cuenat P. Resveratrol in wine: extraction from skin during fermentation and post-fermentation standing of must from gamay grapes. American Journal of Enology and Viticulture. 1996; 47: 287–290.
[14] Pagano C, Marinozzi M, Baiocchi C, Beccari T, Calarco P, Ceccarini MR, *et al*. Bioadhesive polymeric films based on red onion skins extract for wound treatment: an innovative and eco-friendly formulation. Molecules. 2020; 25: 318.
[15] Pagano C, Perioli L, Baiocchi C, Bartoccini A, Beccari T, Blasi F, *et al*. Preparation and characterization of polymeric microparticles loaded with Moringa oleifera leaf extract for exuding wound treatment. International Journal of Pharmaceutics. 2020; 587: 119700.
[16] Chung T. Toxic blaze: the true cost of crop burning. 2021. Available at: https://www.unep.org/news-and-stories/story/toxic-blaze-true-cost-crop-burning (Accessed: 16 August 2021).
[17] Corrieri U. Le biomasse legnose non sono vere energie rinnovabili e il loro uso causa gravi effetti sulla salute. Epidemiologia e Prevenzione. 2019; 43: 300–304. (In Italian)
[18] Turner MC, Andersen ZJ, Baccarelli A, Diver WR, Gapstur SM, Pope CA, *et al*. Outdoor air pollution and cancer: an overview of the current evidence and public health recommendations. CA: a Cancer Journal for Clinicians. 2020; 70: 460–479.
[19] Schraufnagel DE, Balmes JR, Cowl CT, De Matteis S, Jung S, Mortimer K, *et al*. Air pollution and noncommunicable diseases: a review by the forum of international respiratory societies' environmental committee, part 2: air pollution and organ systems. Chest. 2019; 155: 417–426.
[20] Gomiero T, Paoletti MG, Pimentel D. Biofuels: Efficiency, ethics, and limits to human appropriation of ecosystem services. Journal of Agricultural and Environmental Ethics. 2010; 23: 403–434.
[21] Gomiero T. Are biofuels an effective and viable energy strategy for industrialized societies? a reasoned overview of potentials and limits. Sustainability. 2015; 7: 8491–8521.
[22] Freiberg A, Scharfe J, Murta VC, Seidler A. The use of biomass for electricity generation: a scoping review of health effects on

humans in residential and occupational settings. International Journal of Environmental Research and Public Health. 2018; 15: 354.
[23] Sigsgaard T, Forsberg B, Annesi-Maesano I, Blomberg A, Bølling A, Boman C, *et al*. Health impacts of anthropogenic biomass burning in the developed world. The European Respiratory Journal. 2015; 46: 1577–1588.
[24] Guillard V, Gaucel S, Fornaciari C, Angellier-Coussy H, Buche P, Gontard N. The next generation of sustainable food packaging to preserve our environment in a circular economy context. Frontiers in Nutrition. 2018; 5: 121.
[25] Zinnanti C, Schimmenti E, Borsellino V, Paolini G, Severini S. Economic performance and risk of farming systems specialized in perennial crops: an analysis of Italian hazelnut production. Agricultural Systems. 2019; 176: 102645.
[26] Coppola G, Costantini M, Orsi L, Facchinetti D, Santoro F, Pessina D, *et al*. A comparative cost-benefit analysis of conventional and organic hazelnuts production systems in center Italy. Agriculture. 2020; 10: 409.
[27] Granata MU, Bracco F, Catoni R. Carbon dioxide sequestration capability of hazelnut orchards: daily and seasonal trends. Energy, Ecology and Environment. 2020; 5: 153–160.
[28] Nera E, Paas W, Reidsma P, Paolini G, Antonioli F, Severini S. Assessing the resilience and sustainability of a hazelnut farming system in central Italy with a participatory approach. Sustainability. 2020; 12: 343.
[29] Escobar N, Laibach N. Sustainability check for bio-based technologies: a review of process-based and life cycle approaches. Renewable and Sustainable Energy Reviews. 2021; 135: 110213.
[30] Pinales-Márquez CD, Rodríguez-Jasso RM, Araújo RG, *et al*. Circular bioeconomy and integrated biorefinery in the production of xylooligosaccharides from lignocellulosic biomass: A review. Industrial Crops and Products. 2021; 162: 113274.
[31] MEA (Millenium Ecosystem Assessment). Ecosystems and human well-being synthesis. Island Press: Washington. 2005.
[32] Klein A, Bockhorn O, Mayer K, Grabner M. Central European wood species: characterization using old knowledge. Journal of Wood Science. 2016; 62: 194–202.
[33] Persano Oddo L, Piana ML, Ricciardelli D'Albore G. I mieli regionali italiani: Caratterizzazione melissopalinologica. MIPAF: Rome. 2007. (In Italian).
[34] Pausas J, Bladé, C, Valdecantos A, Seva J P, Fuentes D, Alloza J A *et al*. Pines and oaks in the restoration of Mediterranean landscapes of Spain: New perspectives for an old practice - a review. Plant Ecology. 2004; 171: 209–220.
[35] Correia AC, Galla A, Nunes A, Pereira J S. Ecological interactions between cork oak (*Quercus suber* L.) and stone pine (*Pinus pinea* L.): results from a plot experiment. Forests. 2018; 9: 534.
[36] Savoie JM, Largeteau ML. Production of edible mushrooms in forests: trends in development of a mycosilviculture. Applied Microbiology and Biotechnology. 2011; 89: 971–979.
[37] Bankova V, Popova M, Trusheva B. Plant sources of propolis: an update from a chemist's point of view. Natural Product Communications. 2006; 1: 1023–1028.
[38] Frattaroli AR, Ciabò S, Pirone G, Spera DM, Marucci A, Romano B. The disappearance of traditional agricultural landscapes in the Mediterranean basin. The case of almond orchards in Central Italy. Plant Sociology. 2014; 51: 3–15.
[39] Peintner U, Iotti M, Klotz P, Bonuso E, Zambonelli A. Soil fungal communities in a Castanea sativa (chestnut) forest producing large quantities of Boletus edulis sensu lato (porcini): where is the mycelium of porcini? Environmental Microbiology. 2007; 9: 880–889.
[40] Batlle I, Tous J. Carob tree. *Ceratonia siliqua* L. Promoting the conservation and use of underutilized and neglected crops. International Plant Genetic Resources Institute: Rome, Italy. 1997.
[41] El Batal H, Hasib A, Dehbi F, Zaki N, Ouatmane A, Boulli A. Assessment of nutritional composition of Carob pulp (*Ceratonia Siliqua* L.) collected from various locations in Morocco. Journal of Materials and Environmental Science. 2016; 7: 3278–3285.
[42] Govorčin S, Sinković T, Sedlar T. Dimensional stability of olive (*Olea europaea* L.) and teak (*Tectona grandis* L.). Drvna Industrija. 2010; 61: 169–173.
[43] Barbera G, Inglese P, La Mantia T. La tutela e la valorizzazione del paesaggio colturale dei sistemi tradizionali dell'olivo in Italia, Convegno Europeo Il futuro dei sistemi olivicoli in aree marginali: aspetti socio-economici, gestione delle risorse naturali e produzioni di qualità. Matera, 12-13 ottobre 2004. Coference Proceedings: Matera. 2005; 59–76 (In Italian).
[44] Schicchi R, Speciale C, Amato F, Bazan G, Di Noto G, Marino P, *et al*. The monumental olive trees as biocultural heritage of mediterranean landscapes: the case study of Sicily. Sustainability. 2021; 13: 6767.
[45] Allegrini A. Specie multiuso e restauro del paesaggio agroforestale. Tesi di Laurea Magistrale in Scienze Agrarie e Ambientali. Università degli Studi della Tuscia: Viterbo, Italia. 2015. (In Italian).
[46] Holstein N, Tamer S, Weigend M. The nutty world of hazel names - a critical taxonomic checklist of the genus *Corylus* L. (Betulaceae). European Journal of Taxonomy. 2018; 409.
[47] Mayer RH, Aksoy H. Wälder der Türkei. Folia geobot. Phytotax. 1986; 23: 78. (In German)
[48] Browicz K, Zielinski J. Chorology of trees and shrubs in South-West Asia and adjacent regions. Vol. I. Polish Scientific Publishers: Warszawa, Poznan. 1982.
[49] Enescu CM, Houston Durrant T, De Rigo D, Caudullo G. *Corylus avellana* in Europe: distribution, habitat, usage and threats. European Atlas of Forest Tree Species. 2016; 86–87.
[50] Giacomini V, Fenaroli L. La flora. Conosci l'Italia. vol. 2. Touring Club Italiano: Milano. 1958. (In Italian).
[51] Marchesoni V. Storia climatico-forestale dell'Appennino umbro-marchigiano. Annali di Botanica. 1957; 25: 459–497. (In Italian).
[52] Marchesoni V. Importanza del Pino nero, dell'Abete, del Tasso e dell'Agrifoglio nella storia climatico forestale dell'Appennino Umbro-marchigiano. Monti e boschi. 1958; 10: 535–540. (In Italian).
[53] Cheddadi R, de Beaulieu J, Jouzel J, Andrieu-Ponel V, Laurent J, Reille M, *et al*. Similarity of vegetation dynamics during interglacial periods. Proceedings of the National Academy of Sciences of the United States of America. 2005; 102: 13939–13943.
[54] Paganelli A. Histoire paleobotanique. In Guide-Itineraire Excursion Internat. Phytosoc. Italie Centrale (ed. Pedrotti F). 1982; 39–74. (In French).
[55] Roesch M. Evaluation of honey residues from Iron Age hill-top sites in southwestern Germany: implications for local and regional land use and vegetation dynamics. Vegetation History and Archaeobotany. 1999; 8: 105–112.
[56] Feurdean A, Willis KJ, Parr CL, Tanţău I, Fărcaş S. Post-glacial patterns in vegetation dynamics in Romania: homogenization or differentiation? Journal of Biogeography. 2010; 37: 2197–2208.
[57] Bégeot C. Le comportement pollinique du Noisetier (*Corylus avellana*), son rôle comme indicateur d'impacts anthropiques? L'exemple d'un transect dans le sud du Jura. Acta Botanica Gallica. 1998; 145: 271–279. (In French)
[58] Botta R, Valentini N. II nocciolo. Progettazione e coltivazione del corileto. Edagricole-New Business Media. 2018. (In Italian)
[59] Pignatti S. I piani di vegetazione in Italia. Giornale Botanico Italiano. 1979; 113: 411–428. (In Italian)
[60] Gellini R, Grossoni P. Botanica forestale-II. Angiosperme. Edizione Cedam Milano. 1997; 135–139. (In Italian)

[61] Cianfaglione K, Pedrotti F. The vegetation of the Pie' Vettore debris (Sibillini mountains, Central Italy). Vegetation structure and function at multiple spatial, temporal and conceptual scales. 2016; 36: 363–374.
[62] Golub VB, Kuzmina EG. The communities of cl. *Querco-Fagetea* BR.-BL. & Vliegeir *in* Vliegeir 1937 of the Lower Volga Valley. Feddes Repertorium. 1997; 108: 205–218.
[63] Rivas-Martinez S, Costa M. Datos sobre la vegetación y el bioclima del Valle de Arán. Acta Botanica Barcinonensia. 1998; 45: 473–499. (In Spanish)
[64] Ballelli S, Biondi E, Pedrotti F. Un'associazione a *Corylus avellana* e *Carpinus betulus* nell'Appennino Umbro-Marchigiano. Not. Fitosoc. 1980; 16: 47–52. (In Italian)
[65] Liang WJ, Dong DF, Wang GX, Dong FX, Liang LS, Ma QH. Progresses on the hazelnut cross breeding of *Corylus heterophylla* Fisch. x *Corylus avellana* L. In China. Acta Horticulturae. 2012; 940: 31.
[66] Malusà E. Interspecific relationships among *Corylus* species. Acta Horticulturae. 1994; 351: 335–340.
[67] Bhattarai G, Mehlenbacher SA, Smith DC. Eastern filbert blight disease resistance from *Corylus americana* 'Rush' and selection 'Yoder #5' maps to linkage group 7. Tree Genetics & Genomes. 2017; 13: 45.
[68] Boccacci P, Botta R. Investigating the origin of hazelnut (*Corylus avellana* L.) cultivars using chloroplast microsatellites. Genetic Resources and Crop Evolution. 2009; 56: 851–859.
[69] Me G, Valentini N. La corilicoltura in Italia e nel mondo. Petria. 2006; 16: 7–18. (In Italian)
[70] Food and Agriculture Organisation. Faostat. 2021: Avaible at https://www.fao.org/faostat/en/#home. (Accessed: 30 December 2021).
[71] Ministero delle politiche agricole alimentari e forestali. Circonferenze minime indicative per il criterio dimensionale. 2020. Available at: https://www.politicheagricole.it/flex/cm/pages/ServeAttachment.php/L/IT/D/e%252F7%252F4%252FD.be27384a71c33eaf6c06/P/BLOB%3AID%3D11272/E/pdf. (Accessed: 30 December 2021).
[72] Cianfaglione K. Alberi monumentali: importanza, gestione, prospettive e nuove segnalazioni. In: Cianfaglione K. L'importanza degli alberi e del bosco. Cultura, scienza e coscienza del territorio. I: 319–371. Temi: Trento. 2014 (In Italian).
[73] Linnaeus C. Species Plantarum. Exhibentes plantas rite cognitas, ad genera relatas, cum differentiis specificis, nominibus trivialibus, synonymis selectis, locis natalibus, secundum systema sexuale digestas. Imprensis Laurentius Salvius: Stockholm. 1753.
[74] Fuchs L. De Historia Stirpium Commentarii Insignes. Officina Isingriniana: Basilea. 1542.
[75] Mitchell AF. The Trees of Britain and Northern Europe. Collins Publications: Glasgow. 1982.
[76] La nocciola in italia e nel mondo. 2007. Available at: https://agronotizie.imagelinenetwork.com/vivaismo-e-sementi/2007/09/21/la-nocciola-in-italia-e- nelmondo/4138 (In Italian) (Accessed: 21 September 2021).
[77] Franco S, Pancino B, Cristofori V. Hazelnut production and local development in Italy. Acta Horticulturae. 2014; 1052: 48.
[78] Pellegrini N, Serafini M, Salvatore S, Del Rio D, Bianchi M, Brighenti F. Total antioxidant capacity of spices, dried fruits, nuts, pulses, cereals and sweets consumed in Italy assessed by three different in vitro assays. Molecular Nutrition & Food Research. 2006; 50: 1030–1038.
[79] Bertolino M, Belviso S, Dal Bello B, Ghirardello D, Giordano M, Rolle L, *et al*. Influence of the addition of different hazelnut skins on the physicochemical, antioxidant, polyphenol and sensory properties of yogurt. LWT - Food Science and Technology. 2015; 63: 1145–1154.
[80] Cravotto G, Mariatti F, Gunjevic V, Secondo M, Villa M, Parolin J, *et al*. Pilot scale cavitational reactors and other enabling technologies to design the industrial recovery of polyphenols from agro-food by-products, a technical and economical overview. Foods. 2018; 7.
[81] Ozyurt VH, Otles S. Hazelnut testa as a by-product: Nutritional composition, antioxidant activity, phenolic compound profile and dietary fiber content. Journal of Faculty of Pharmacy of Ankara University. 2018; 42: 38–57.
[82] Saricaoglu FT, Gul O, Besir A, Atalar I. Effect of high pressure homogenization (HPH) on functional and rheological properties of hazelnut meal proteins obtained from hazelnut oil industry by-products. Journal of Food Engineering. 2018; 233: 98–108.
[83] Angelica Vazquez-Flores A, Alberto Núñez-Gastélum J, Alvarez-Parrilla E, Wall-Medrano A, Rodrigo-GarcÍa J, Fernando Ayala-Zavala J, *et al*. By-products of the nut and peanut agro-industry as sources of phytochemicals suitable for the nutraceutical and food industries. plant food by-products. 2018; 201–220.
[84] Manna L, Bugnone CA, Banchero M. Valorization of hazelnut, coffee and grape wastes through supercritical fluid extraction of triglycerides and polyphenols. The Journal of Supercritical Fluids. 2015; 104: 204–211.
[85] Yurttas HC, Schafer HW, Warthesen JJ. Antioxidant activity of nontocopherol hazelnut (*Corylus* spp.) phenolics. Journal of Food Science. 2000; 65: 276–280.
[86] Maguire LS, O'Sullivan SM, Galvin K, O'Connor TP, O'Brien NM. Fatty acid profile, tocopherol, squalene and phytosterol content of walnuts, almonds, peanuts, hazelnuts and the macadamia nut. International Journal of Food Sciences and Nutrition. 2004; 55: 171–178.
[87] Delgado T, Malheiro R, Pereira JA, Ramalhosa E. Hazelnut (*Corylus avellana* L.) kernels as a source of antioxidants and their potential in relation to other nuts. Industrial Crops and Products. 2010; 32: 621–626.
[88] Nunzio MD. Hazelnuts as source of bioactive compounds and health value underestimated food. Current Research in Nutrition and Food Science Journal. 2019; 7: 17–28.
[89] Zabaras D. Olive oil adulteration with hazelnut oil and analytical approaches for its detection. Olives and Olive Oil in Health and Disease Prevention. 2010; 881: 441–450.
[90] Ojeda-Amador RM, Fregapane G, Salvador MD. Chemical characterization of virgin almond and hazelnut oils and their by-products. European Journal of Lipid Science and Technology. 2019; 121: 1900114.
[91] Monika M, Anna K. Nut oils and their dietetic and cosmetic significance: a review. Journal of Oleo Science. 2019; 68: 111–120.
[92] Xu YX, Hanna MA, Josiah SJ. Hybrid hazelnut oil characteristics and its potential oleochemical application. Industrial Crops and Products. 2007; 26: 69–76.
[93] Vicario R. Italian liqueurs. The history and art of a creation. Aboca Edizioni: Sansepolcro, Italy. 2014.
[94] Aydoğan M, Demiryürek K, Abacı NI. World hazelnut trade networks. Acta Horticulturae. 2018; 1266: 429–436.
[95] Servadei A, Zangheri S, Masutti L. Entomologia generale ed applicata. CEDAM: Padova. 1972; 320–321. (In Italian).
[96] Tremblay E. Entomologia applicata. Liguori Editore: Napoli. 2003. (In Italian)
[97] Delprete C, Sesana R. Mechanical characterization of kernel and shell of hazelnuts: Proposal of an experimental procedure. Journal of Food Engineering. 2014; 124: 28–34.
[98] Walton VM, Chambers U, Olsen JL. The current status of the newly invasive hazelnut aphid in oregon hazelnut orchards. Acta Horticulturae. 2009; 845: 479–486.
[99] Moraglio ST, Bosco L, Tavella L. *Halyomorpha halys* invasion:

a new issue for hazelnut crop in northwestern Italy and western Georgia? Acta Horticulturae. 2018; 379–384.

[100] Yuan B, Lu M, Eskridge KM, Isom LD, Hanna MA. Extraction, identification, and quantification of antioxidant phenolics from hazelnut (*Corylus avellana* L.) shells. Food Chemistry. 2018; 244: 7–15.

[101] Panzella L, Moccia F, Nasti R, Marzorati S, Verotta L, Napolitano A. Bioactive phenolic compounds from agri-food wastes: an update on green and sustainable extraction methodologies. Frontiers in nutrition. 2020; 7: 60.

[102] La nuova provincia. Rade al suolo un bosco e ci pianta un noccioleto denuncia e multa da 2300 euro. 2019. Available at: https://lanuovaprovincia.it/cronaca/rade-al-suolo-un-bosco-e-ci-pianta-un-noccioleto-denuncia-e-multa-da2300-euro. (Accessed: 30 December 2021).

[103] Lippolis I. Viterbese, I noccioleti soffocano la biodiversità. 2015. Available at: https://www.vglobale.it/2015/10/30/viterbese-i-noccioleti-soffocano-la-biodiversita. (Accessed: 30 December 2021).

[104] Cronache maceratesi. Noccioleti, appello di Italia Nostra: “l’impatto va valutato gli amministratori si facciano sentire”. 2019. https://www.cronachemaceratesi.it/2019/10/27/noccioleti-appello-di-italia-nostra-limpatto-va-valutato-gliamministratori-si-facciano-sentire/1318271. (Accessed: 30 December 2021).

[105] Iovene BE. Che nocciola sia - I vivai della regina. Documentary video. Report, Rai - Radiotelevisione Italiana Spa. 2021. Available at: https://www.rai.it/programmi/report/inchieste/Monoculture-o-Biodiversita-cf1eff13-9494-4931-9918-8655fc1b92eb.html. (Accessed: 30 December 2021).

[106] Manuale di ingegneria naturalistica sistemazione dei versanti–Regione Lazio, 2006–Assessorato all’Ambiente e Cooperazione tra i popoli Direzione Regionale Ambiente e Cooperazione tra i popoli: 2006; 3: 866. (In Italian).

[107] Tammaro F. Manuale per il recupero ambientale con tecniche di Ingegneria Naturalistica dei detrattori della Regione Abruzzo. Regione Abruzzo: 1998. (In Italian).

[108] Bernetti G. Selvicoltura speciale. UTET: Torino. 1995. (In Italian).

[109] Derouin S. Nuts about agroforestry: can hazelnuts transform midwest farming? 2021. Available at: https://news.mongabay.com/2021/04/nuts-about-agroforestry-in-the-u-s-midwest-can-hazelnuts-transform-farming/. (Accessed: 28 April 2021).

[110] Bischetti G B, Chiaradia E A, Simonato T, Speziali B, Vitali B, Vullo P, *et al*. Root strength and root area ratio of forest species in Lombardy (Northern Italy). In Stokes A, Spanos I, Norris JE, Cammeraat E (eds.) Eco-and ground bio-engineering: the use of vegetation to improve slope stability (pp. 31–41). Developments in Plant and Soil Sciences. 2007.

[111] Schirone B. La gestione delle aree prossime alle linee elettriche ad alta e altissima tensione. La modellizzazione della gestione forestale. Rapporto. Terna-WWF Italia. 2016. (In Italian).

[112] Bocquet M. Boutures de noisetiers “en vert” inoculées avec Mycelium truffier”. Bulletin de la Société d’Histoire Naturelle de Savoie. 1973; 42: 11–16. (In French)

[113] Olivier JM, Mamoun M. Compétition entre symbiotes sur jeunes noisetiers truffiers. Acta Botanica Gallica. 1994; 141: 559–563. (In French)

[114] Pargney J, Leduc J. Etude ultrastructurale de l’association mycorhizienne Noisetier/Truffe (*Corylus avellana/Tuber melanosporum*). Bulletin De La SociéTé Botanique De France. Lettres Botaniques. 1990; 137: 21–34.

[115] Santelices R, Palfner G. Controlled rhizogenesis and mycorrhization of hazelnut (*Corylus avellana* L.) cuttings with black truffle (*Tuber melanosporum* Vitt.). Chilean Journal of Agricultural Research. 2010; 70: 204–212.

[116] Roversi A. Coltivare il nocciolo. Impianto e gestione del corileto da reddito. L’Informatore Agrario: Verona. 2020; 144. (In Italian).

[117] Fischer C, Oliach D, Bonet L, José A. Best practices for cultivation of truffles. Forest Sciences Centre of Catalonia and Yaşama Dair Vakıf. 2017.

[118] Hinkamp D. Filberts-nutty trees, shrubs and trubs. Garden Notes: 1999; 14.

[119] Molnar TJ. *Corylus*. Wild crop relatives: genomic and breeding resources: forest trees. In: Kole C, ed. Springer Berlin Heidelberg. 2011;15-48.

[120] Mehlenbacher SA, Smith DC, McCluskey RL. ‘Burgundy lace’ ornamental hazelnut. Horticultural Science. 2018; 53: 387–390.

[121] Shahidi F, Alasalvar C, Liyana-Pathirana CM. Antioxidant phytochemicals in hazelnut kernel (*Corylus avellana* L.) and hazelnut byproducts. Journal of Agricultural and Food Chemistry. 2007; 55: 1212–1220.

[122] Contini M, Frangipane MT, Massantini R. Chapter 72 - Antioxidants in hazelnuts (*Corylus avellana* L.). In Preedy VR, Watson RR (eds.) Nuts and Seeds in Health and Disease Prevention (pp. 611–625). Academic Press: London. 2011.

[123] Xu Y, Sismour EN, Parry J, Hanna MA, Li H. Nutritional composition and antioxidant activity in hazelnut shells from US-grown cultivars. International Journal of Food Science and Technology. 2012; 47: 940–946.

[124] Wani IA, Ayoub A, Bhat NA, Dar AH, Gull A. Hazelnut BT. In Nayik GA, Gull A (eds.) Antioxidants in vegetables and nuts - properties and health benefits. Springer: Singapore. 2020; 559–572.

[125] Romaní A, Rocha CMR, Michelin M, Domingues L, Teixeira JA. Valorization of lignocellulosic-based wastes. Current Developments in Biotechnology and Bioengineering. 2020; 383–410.

[126] Lewicka K. Activated carbons prepared from hazelnut shells, walnut shells and peanut shells for high CO2 adsorption. Polish Journal of Chemical Technology. 2017; 19: 38–43.

[127] Fuso A, Risso D, Rosso G, Rosso F, Manini F, Manera I, Caligiani A. Potential valorization of hazelnut shells through extraction, purification and structural characterization of prebiotic compounds: a critical review. Foods. 2021; 10: 1197.

[128] Pérez-Armada L, Rivas S, González B, Moure A. Extraction of phenolic compounds from hazelnut shells by green processes. Journal of Food Engineering. 2019; 255: 1–8.

[129] Balart JF, García-Sanoguera D, Balart R, Boronat T, Sánchez-Nacher L. Manufacturing and properties of biobased thermoplastic composites from poly(lactid acid) and hazelnut shell wastes. Polymer Composites. 2018; 39: 848–857.

[130] Contini M, Baccelloni S, Massantini R, Anelli G. Extraction of natural antioxidants from hazelnut (*Corylus avellana* L.) shell and skin wastes by long maceration at room temperature. Food Chemistry. 2008; 110: 659–669.

[131] Pelvan E, Olgun EÖ, Karadağ A, Alasalvar C. Phenolic profiles and antioxidant activity of Turkish Tombul hazelnut samples (natural, roasted, and roasted hazelnut skin). Food Chemistry. 2018; 244: 102–108.

[132] Durmaz G, Gökmen V. Effect of refining on bioactive composition and oxidative stability of hazelnut oil. Food Research International. 2019; 116: 586–591.

[133] Rusu ME, Fizeșan I, Pop A, Gheldiu A, Mocan A, Crișan G, *et al*. Enhanced recovery of antioxidant compounds from hazelnut (*Corylus avellana* L.) involucre based on extraction optimization: phytochemical profile and biological activities. Antioxidants. 2019; 8: 460.

[134] Routray W, Orsat V. Agricultural and food industry by-products: source of bioactive components for functional beverages. Nutrients in Beverages. 2019; 543–589.

[135] Herrera R, Hemming J, Smeds A, Gordobil O, Willför S, Labidi J. Recovery of bioactive compounds from hazelnuts and walnuts shells: quantitative-qualitative analysis and chromatographic purification. Biomolecules. 2020; 10: 1363.
[136] Tunçil YE. Dietary fibre profiles of Turkish Tombul hazelnut (*Corylus avellana* L.) and hazelnut skin. Food Chemistry. 2020; 316: 126338.
[137] Albuquerque BR, Heleno SA, Oliveira MBPP, Barros L, Ferreira ICFR. Phenolic compounds: current industrial applications, limitations and future challenges. Food & Function. 2021; 12: 14–29.
[138] Kocaman S, Ahmetli G. Effects of various methods of chemical modification of lignocellulose hazelnut shell waste on a newly synthesized bio-based epoxy composite. Journal of Polymers and the Environment. 2020; 28: 1190–1203.
[139] Bottone A, Cerulli A, D'Urso G, Masullo M, Montoro P, Napolitano A, *et al*. Plant specialized metabolites in hazelnut (*Corylus avellana*) kernel and byproducts: an update on chemistry, biological activity, and analytical aspects. Planta Medica. 2019; 85: 840–855.
[140] Ramalhosa E, Delgado T, Estevinho L, Pereira JA. Hazelnut (*Corylus avellana* L.) cultivars and antimicrobial activity. In Preedy V, Watson R (eds.) Nuts and seeds in health and disease prevention (pp. 627–636). 1st edn. Academic Press: Cambridge Massachusetts. 2011.
[141] Di Michele A, Pagano C, Allegrini A, Blasi F, Cossignani L, Raimo ED, *et al*. Hazelnut shells as source of active ingredients: extracts preparation and characterization. Molecules. 2021; 26: 6607.
[142] Esposito T, Sansone F, Franceschelli S, Del Gaudio P, Picerno P, Aquino RP, Mencherini T. Hazelnut (*Corylus avellana* L.) shells extract: phenolic composition, antioxidant effect and cytotoxic activity on human cancer cell lines. International Journal of Molecular Sciences. 2017; 18: 392.
[143] Abbaszadeh H, Keikhaei B, Mottaghi S. A review of molecular mechanisms involved in anticancer and antiangiogenic effects of natural polyphenolic compounds. Phytotherapy Research. 2019; 33: 2002–2014.
[144] Oyenihi AB, Smith C. Are polyphenol antioxidants at the root of medicinal plant anti-cancer success? Journal of Ethnopharmacology. 2019; 229: 54–72.
[145] Kumar S, Kushwaha R, Verma ML. Recovery and utilization of bioactives from food processing waste. Biotechnological Production of Bioactive Compounds. 2020; 52: 37–68.
[146] Riddle JM. Discorides on pharmacy and medicine. 1st edn. University of Texas Press: Austin, Texas. 1986.
[147] Durazzo A, Lucarini M, Souto EB, Cicala C, Caiazzo E, Izzo AA, *et al*. Polyphenols: a concise overview on the chemistry, occurrence, and human health. Phytotherapy Research. 2019; 33: 2221–2243.
[148] Derosa G, Maffioli P, D'Angelo A, Di Pierro F. A role for quercetin in coronavirus disease 2019 (COVID-19). Phytotherapy Research. 2021; 35: 1230–1236.
[149] Stévigny C, Rolle L, Valentini N, Zeppa G. Optimization of extraction of phenolic content from hazelnut shell using response surface methodology. Journal of the Science of Food and Agriculture. 2007; 87: 2817–2822.
[150] Ciurlia L, Bleve M, Rescio L. Supercritical carbon dioxide coextraction of tomatoes (*Lycopersicum esculentum* L.) and hazelnuts (*Corylus avellana* L.): A new procedure in obtaining a source of natural lycopene. The Journal of Supercritical Fluids. 2009; 49: 338–344.
[151] Odabaş H İ, Koca I. Application of response surface methodology for optimizing the recovery of phenolic compounds from hazelnut skin using different extraction methods. Industrial Crops and Products. 2016; 91:114–124.
[152] Çöpür Y, Güler C, Akgül M, Taşçıoğlu C. Some chemical properties of hazelnut husk and its suitability for particleboard production. Building and Environment. 2007; 42: 2568–2572.
[153] Guney M S. Effective utilization and physical conversion of biomass, and some properties of hazelnut husk. Journal of Engineering Research and Applied Science.2019; 8: 1185–1189.
[154] Hebda T, Brzychczyk B, Francik S, Pedryc N. Evaluation of suitability of hazelnut shell energy for production of biofuels. Engineering for Rural Development. 2018; 5: 23–25.
[155] Sullivan GT, Ozman-Sullivan SK, Akbasli O, Sahin M. A tribute to the hazelnut plant (*Corylus* spp.). The multiple uses of nature's magnificent gifts. Acta Hortic. 2014; 1052: 51.
[156] Rukavina H, Furlan M, Vounatsos KEMNP, Bau L, Francescato V, Almeida T, *et al*. Developing the sustainable market of residential Mediterranean solid biofuels. 2017. Available at: http://biomasudplus.eu/wp-content/uploads/2017/09/D2.1-Market_report_Consolitated-6.pdf. (Accessed: 30 December 2021).
[157] Midilli A, Dogru M, Howarth C R, Ayhan T. Hydrogen production from hazelnut shell by applying airblown downdraft gasification technique. International Journal of Hydrogen Energy. 2001; 26: 29–37.
[158] Dogru M, Howarth CR, Akay G, Keskinler B, Malik AA. Gasification of hazelnut shells in a downdraft gasifier. Energy. 2002; 27: 415–427.
[159] Montenegro Camacho YS, Bensaid S, Ruggeri B, Restuccia L, Ferro G, Mancini G, *et al*. Valorisation of by-products/waste of agro-food industry by the pyrolysis process. Journal of Advanced Catalysis Science and Technology. 2016; 3.
[160] Xu S, Ou C, Chen Y, Xiao H, Fu C, Lu W, *et al*. Study on the pyrolysis characteristics of walnut processing by-products. IOP Conference Series: Earth and Environmental Science. 2020; 508: 012126.
[161] Lui J, Chen WH, Tsang DCW, You S. A critical review on the principles, applications, and challenges of waste-to-hydrogen technologies. Renewable and Sustainable Energy Reviews. 2020; 134: 110365.
[162] Ivanović S, Avramović N, Dojčinović B, Trifunović S, Novaković M, Tešević V, *et al*. Chemical composition, total phenols and flavonoids contents and antioxidant activity as nutritive potential of roasted hazelnut skins (*Corylus avellana* L.). Foods. 2020; 9: 430.
[163] Locatelli M, Travaglia F, Cosïson JD, Martelli A, Stévigny C, Arlorio M. Total antioxidant activity of hazelnut skin (Nocciola Piemonte PGI): impact of different roasting conditions. Food Chemistry. 2010; 119: 1647–1655.
[164] Özdemir KS, Yılmaz C, Durmaz G, Gökmen V. Hazelnut skin powder: a new brown colored functional ingredient. Food Research International. 2014; 65: 291–297.
[165] Contini M, Baccelloni S, Massantini R, Anelli G, Manzi L, Merendino N. In vitro and in vivo antioxidant potential of phenolic extracts obtained from hazelnut skin by-products. Acta Horticulturae. 2009; 717–722.
[166] Del Rio D, Calani L, Dall'Asta M, Brighenti F. Polyphenolic composition of hazelnut skin. Journal of Agricultural and Food Chemistry. 2011; 59: 9935–9941.
[167] Spagnuolo L, Della Posta S, Fanali C, Dugo L, De Gara L. Antioxidant and antiglycation effects of polyphenol compounds extracted from hazelnut skin on advanced glycation end-products (AGEs) formation. Antioxidants. 2021; 10: 424.
[168] Montella R, Coïsson JD, Travaglia F, Locatelli M, Malfa P, Martelli A, *et al*. Bioactive compounds from hazelnut skin (*Corylus avellana* L.): Effects on *Lactobacillus plantarum* P17630 and *Lactobacillus crispatus* P17631. Journal of Functional Foods. 2013; 5: 306–315.
[169] Renna M, Lussiana C, Malfatto V, Gerbelle M, Turille G, Men-

dana C, *et al*. Evaluating the suitability of hazelnut skin as a feed ingredient in the diet of dairy cows. Animals. 2020; 10: 1653.
[170] Cikrikci S, Demirkesen I, Mert B. Production of hazelnut skin fibres and utilisation in a model bakery product. Quality Assurance and Safety of Crops and Foods. 2016; 8: 195–206.
[171] Cabo S, Aires A, Carvalho R, Pascual-Seva N, Silva AP, Gonçalves B. *Corylus avellana* L. husks an underutilized waste but a valuable source of polyphenols. Waste and Biomass Valorization. 2021; 12: 3629–3644.
[172] Zieleniewska M, Szczepkowski L, Krzyzowska M, Leszczynski MK, Ryszkowska J. Rigid polyurethane foam composites with vegetable filler for application in the cosmetics industry. Polimery. 2021; 61: 807–814.
[173] Çöpür Y, Güler C, Taşçıoğlu C, Tozluoğlu A. Incorporation of hazelnut shell and husk in MDF production. Bioresource Technology. 2008; 99: 7402–7406.
[174] Çöpür Y, Tozluoglu A, Özkan M. Evaluating pretreatment techniques for converting hazelnut husks to bioethanol. Bioresource Technology. 2013; 129: 182–190.
[175] Oliveira I, Sousa A, Valentão P, Andrade PB, Ferreira ICFR, Ferreres F, *et al*. Hazel (*Corylus avellana* L.) leaves as source of antimicrobial and antioxidative compounds. Food Chemistry. 2007; 105: 1018–1025.
[176] Walking sticks. A guide to wooden walk sticks. 2018. Available at: https://www.walkingsticks.co.uk/blog/a-guide-to-wooden-walking-sticks.html. (Accessed: 30 December 2021).
[177] Borland S. Tremendous trees – hazel. 2015. Available at: https://www.highlandtitles.com/blog/tremendous-trees-hazel/ (Accessed: 17 September 2015).
[178] Monarca D, Cecchini M, Colantoni A, Di Giacinto S, Marucci A, Longo L. Assessment of the energetic potential by hazelnuts pruning in Viterbo's area. Journal of Agricultural and Food Chemistry. 2013; 44: 591–594.
[179] Proto AR, Longo L, Gambella F, Zimbalatti G, Macrì G, Gallucci F, *et al*. Energetic characteristics of syngas obtained from gasification of hazelnut prunings. Procedia - Social and Behavioral Sciences. 2016; 223: 835–840.
[180] Abenavoli LM, Longo L, Proto AR, Gallucci F, Ghignoli A, Zimbalatti G, *et al*. Characterization of biochar obtained from olive and hazelnut prunings and comparison with the standards of european biochar certificate (E.B.C.). Procedia - Social and Behavioral Sciences. 20156; 223: 698–705.
[181] Kalus K, Koziel JA, Opaliński S. A review of biochar properties and their utilization in crop agriculture and livestock production. Applied Sciences. 2019; 9: 3494.
[182] Reed EY, Chadwick DR, Hill PW, Jones DL. Critical comparison of the impact of biochar and wood ash on soil organic matter cycling and grassland productivity. Soil Biology and Biochemistry. 2017; 110: 134–142.
[183] Ding Y, Liu Y, Liu S, Li Z, Tan X, Huang X, *et al*. Biochar to improve soil fertility. A review. Agronomy for Sustainable Development. 2016; 36: 36.
[184] Zhu Q, Peng X, Huang T. Contrasted effects of biochar on maize growth and N use efficiency depending on soil conditions. International Agrophysics. 2015; 29: 257–266.
[185] Datema MR, Zuidmeer-Jongejan L, Asero R, Barreales L, Belohlavkova S, de Blay F, *et al*. Hazelnut allergy across Europe dissected molecularly: a EuroPrevall outpatient clinic survey. The Journal of Allergy and Clinical Immunology. 2015; 136: 382–391.
[186] Calvani M, Asero R, Bergamini M, La Grutta S, Pucci N. La diagnosi di allergia alla nocciola. Rivista di Immunologia e Allergologia Pediatrica. 2010; 5: 21–32. (In Italian)
[187] Nebbia S, Lamberti C, Cirrincione S, Acquadro A, Abbà S, Ciuffo M, *et al*. Oleosin Cor a 15 is a novel allergen for Italian hazelnut allergic children. Pediatric Allergy and Immunology. 2021; 32: 1743–1755.
[188] Pucci N, Asero R, Calvani M, Indirli GC, La Grutta S. La diagnosi di allergia alle profiline. Rivista di Immunologia e Allergologia Pediatrica. 2011; 6: 3–15. (In Italian)