The potential of hazelnut trees (Corylus avellana L.) in an agroforestry context in Belgium and The Netherlands

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« If you don’t take change by the hand,
it will take you by the throat.”

Winston Churchill

Host Institution and scholarship

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Abstract

There is a growing interest in planting hazel trees in an agroforestry context in Belgium and The Netherlands. However, commercial hazelnut cultivation and research in these areas remain rare. Therefore, a hazelnut trial has been implemented by ILVO (Flanders, Belgium) to assess and compare productivity of eight different varieties of hazelnut, along with interactions due to mixed cropping systems, as well as on nut quality and taste. Marketing and economic opportunities and difficulties have been looked into by taking semi-structured interviews. The present study analyzed the productivity through the total weight of hazelnut fallen per tree and by relating it to the variety and the intensity of chicken pressure on the field. The results showed that in 2020, the 'Kentish Cob' variety had the highest production per tree. The statistical model also showed the positive impact of the presence of chicken on the field on the production and on regulating the damages caused by the hazelnut weevil. The analysis of hazelnut market showed both the great potential for producing high-quality hazelnuts, and that markets are the as yet positive response of the markets on suchlike product.

Résumé

Il y a un intérêt croissant pour la plantation de noisetiers dans un contexte agroforestier en Belgique et aux Pays-Bas. Cependant, la culture de noisettes à des fins commerciales ainsi que la recherche scientifique sur ce sujet restent anecdotiques dans ces pays. Par conséquent, un essai agroforestier a été mis en place par ILVO (Flandre, Belgique) pour évaluer et comparer la productivité de huit variétés différentes de noisetiers, ainsi que des interactions de par la mixité du système ainsi que la qualité et le goût des noisettes. Les opportunités et difficultés économiques et de commercialisation ont été analysées grâce à la réalisation d'interviews semi-directives. La présente étude a analysé la productivité via le poids total de noisettes produites par arbre et en le reliant à la variété et à l'intensité de poules présentent sur le terrain. Les résultats ont montré qu'en 2020, la variété 'Longue d'Espagne' a eu la plus forte production par arbre. Le modèle statistique a également montré un impact positif de la présence de poules sur le terrain sur la production et sur la régulation des dégâts dus au charançon de la noisette. L'analyse de marché a révélé le haut potentiel d'une production de noisettes de haute qualité en Belgique et aux Pays-Bas et que les consommateurs réagissent déjà positivement à un tel produit.

Overzicht

Er is een groeiende belangstelling voor het planten van hazelaars in het kader van agrobosbouw in België en Nederland. Commerciële hazelnootteelt en -onderzoek in deze gebieden blijven echter zeldzaam. Daarom heeft ILVO (Vlaanderen, België) een hazelnootstudie uitgevoerd om de productiviteit van acht verschillende hazelnoot variëteiten, samen met interacties als gevolg van gemengde teeltsystemen, en de kwaliteit en smaak van de noten, te beoordelen en vergelijken. Marketingkansen en -problemen zijn onderzocht door het afnemen van semi-gestructureerde interviews. De huidige studie analyseerde de productiviteit door het totale gewicht gevallen hazelnoot per boom te meten met de variëteit en de intensiteit van de kippendruk op het veld. De resultaten toonden aan dat de variëteit 'Kentish Cob' in 2020 de hoogste productie per boom had. Het statistische model toonde ook de positieve impact van de aanwezigheid van kippen op het veld aan, op de productie en het reguleren van de schade aangericht door de hazelnootboorder. De analyse van de hazelnootmarkt toonde zowel het grote potentieel voor het produceren van hoogkwalitatieve hazelnoten aan, als de reeds positieve respons van de markten op een dergelijk product.

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Foreword

The structure of this paper is presented in two sections. The first part (Section I) is a State of the Art based on the literature and semi-structured interviews of stakeholders and key-informed persons. Two persons have been formally interviewed:

- Ton Baltissen: President of the Dutch Nut Association created in 2017 which has 74 members across Belgium and The Netherlands.
- Harm Tuenter: hazelnut grower since 1994.

The second part of this paper (Section II) is written as a scientific paper.

Section I

STATE OF THE ART

1. Overview of world hazelnut production

There are two types of market for hazelnuts: in-shell hazelnuts and shelled hazelnuts (kernels). The market of shelled hazelnut is the most important, representing 95% of the total traded volume (Germain and Sarraquigne, 2004). The database of the FAO shows that the world hazelnut production (in-shell) in 2018 was around 900 000 tons (Table 1). In the last ten years, Turkey alone accounted for almost 65% of the world production, followed by Italy, with around 12%. Production has fluctuated from year to year in quite big proportions, depending on the climatic conditions (FAO, 2000). Turkish production is stagnating around 550 00 tons, while most of the countries listed in table 1 show an increase of minimum 30% and up to over 300% in Chile and Uzbekistan between 2010 and 2018. On the other hand, the production in Georgia and Spain has decreased by 40% and 47% respectively.

The rest of the world production is made by countries producing less than 2 000 tonnes; Croatia, Belarus, Romania; Tajikistan, Greece, Bulgaria, Armenia, Mongolia, Republic of Moldova, Portugal, Slovenia, Hungary, Tunisia, Cyprus, Ukraine and Denmark, producing all together around 8 000 tonnes (less than 1% of the world production). More than half of the world production is traded. Importing countries are mainly Western countries (Germain and Sarraquigne, 2004).

Table 1 - World hazelnut production (in-shell) (countries with a production over 2 000 tons) from 2010 to 2018 (in thousands of tons)

	2010	2011	2012	2013	2014	2015	2016	2017	2018
World	874	767	947	893	729	963	764	1021	889
Turkey	600	430	660	549	450	646	420	675	515
Italy	90	129	85	113	75	102	121	131	133
Azerbaijan	29	33	30	31	30	32	34	46	52
United States of America	25	35	36	41	33	28	40	29	46
China	20	22	23	23	24	26	24	25	25
Georgia	29	31	25	40	34	35	30	21	17
Iran (Islamic Republic of)	18	19	20	21	10	17	16	16	16
France	10	7	10	8	11	9	13	11	15
Chile	2	5	6	10	6	6	9	9	9
Spain	15	18	14	15	14	11	10	10	8
Poland	3	3	4	5	6	5	6	5	7
Serbia	0	0	0	0	0	4	4	4	5
Kyrgyzstan	3	4	4	4	4	4	4	4	4
Uzbekistan	1	3	2	3	3	4	4	4	4

Source : FAO. (http://www.fao.org/faostat/en/#data/QC)

2. Supply chain in EU

Figure 1 shows the marketing channels through which hazelnuts are marketed in the EU (IPD, 2014). The three grey boxes at the top show the three stages of the supply chain structure, the blue boxes below detail the key actors. Exporting countries almost only provide a raw product, in-shell or shelled hazelnuts; most of the other processing activities take place within the importing countries (IPD, 2014). The EU market imports over 65% of Turkish hazelnut production (Atici, 2013). As the demand exceeds the supply, Turkish exporters control the market, not importers (Lundell et al., 2004).

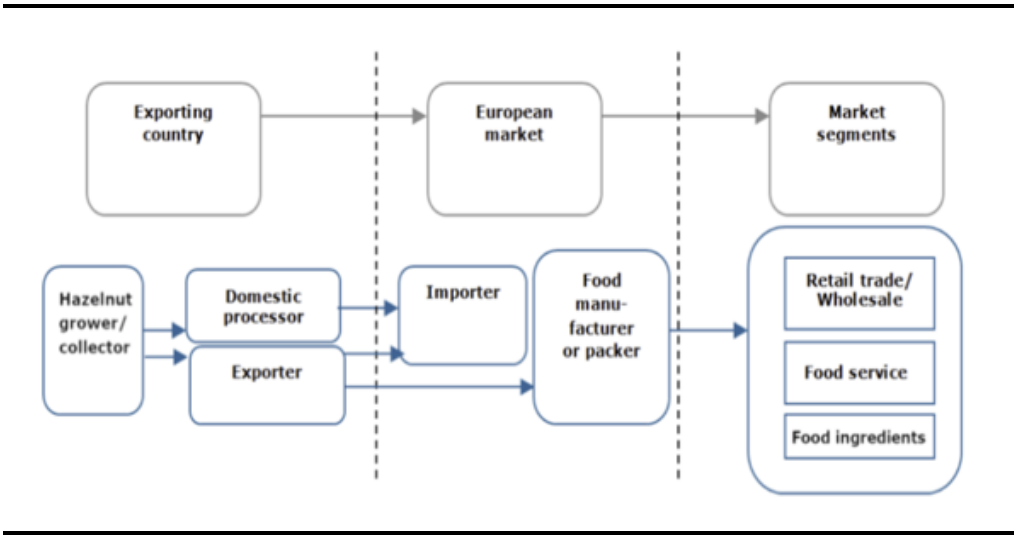


Figure 1 - Market channels for hazelnuts in EU (source: IPD, 2014).

The inventory of hazelnut research of the FAO reports that Turkey alone covers more than 80% of the world exports, and Europe is its largest importer. Italy is the second largest exporting country with nearly 15% in export. The domestic processing segment showed in figure 1 concerns, for Turkey, the shelling of the hazelnuts before exporting, but also blanching, roasting, slicing, mincing or transforming into paste. This sector is expanding as processing capacities increase. Of the total volume exported by Turkey, nearly 70% are shelled hazelnuts and 30% are roasted hazelnuts (Lundell et al., 2004).

On the European market, there are two broad market segments: manufacturing industry and end-consumers (IPD, 2014). The manufacturing industry uses up to 90% of the hazelnut supply, with 70% just for the chocolate industry. Only 10% are sold as an unprocessed product. After the hazelnuts are transformed in the importing countries, they can be exported once again as a processed final product (Lundell et al., 2004).

3. Current status of hazelnut production in Belgium and the Netherlands

Initially native of Asia Minor, the oceanic temperate climate Belgium and the Netherlands offer has led to the naturalization of hazel trees over this region (and in a large part of Europe) (Germain and Sarraquigne, 2004). Hazelnut trees are now widely naturalized and easily found in the understorey of deciduous forests and as hedges or coppices (Crawford, 2015). However, its commercial cultivation remains rare in Belgium and the Netherlands. According to Statbel, the total surface of hazelnut orchards in Belgium in 2019 was around 7.61 ha, with 5.22 ha in Flanders and 1.93 ha in Wallonia. Two farmers in Liège (Wallonia) produce small quantities of hazelnuts as diversification to their main crops. Their production is mainly sold for local market and restaurants and fresh hazelnuts are sold in Paris through a French wholesaler (Gretry, 2019 and Mélon, 2016)

4. Opportunities and possibilities of hazelnut production in Belgium and The Netherlands

As three quarters of the world imports into Europe are destined for Germany, Italy, France, The Netherlands, Belgium, Switzerland and Austria, there is a clear opportunity to develop a local market in those countries. However, prices are mainly determined by production conditions in Turkey (Germain and Sarraquigne, 2004), it is therefore hard to align with Turkish prices regarding production costs in Belgium and The Netherlands. Facing the Turkish world leader in this sector, it is preferable to develop a high-end market in quality and taste, along with the sustainability aspect of local and integrated agricultural systems. Moreover, customers nowadays have new requirements on local supply and healthier products. Since nuts have been added to the nutrition pyramid in 2019, their popularity has increased outstandingly (pers. comm. Ton Baltissen). They can also contribute to the protein transition. Indeed, there is a fast-growing need to produce more plant-based nutrients as an alternative to animal proteins. Nut proteins can be a substantial part of the solution to provide the growing world population with sufficient proteins (Ministry of Agriculture of The Netherlands, 2019).

Indeed, Turkey might be the largest producer of hazelnut in the world (FAO, 2020), the sustainability of its production faces various issues putting it on a knife-edge. The 2019 UTZ Certified Hazelnut Program by the Rainforest Alliance states that these issues are related to old orchards (resulting in low productivity and quality), low maintenance of trees, bad drying conditions (nuts drying in open air but high humidity levels, causing fungi), farmers relying on internal migrant workers for the short harvest period (involving therefore child labor), low wages and low environmental standards and knowledge about good agricultural practices putting a thread on the environment. New spots of sustainable and local production areas are therefore needed in our regions to meet society's high standards.

The demand for in-shell hazelnuts is a stagnant market, or even slightly declining in France (Germain and Sarraquigne, 2004); it is possible that the same trend can operate in Belgium and The Netherlands, as these three countries are similar. On average, this type of hazelnut is sold around 4€/kg here compared to 2€/kg for Turkish hazelnuts. The hazelnut kernels market is much more important (Germain and Sarraquigne, 2004) and they are sold around 13€/kg directly at the farm; this price can reach 15€/kg for white kernels (pers. comm. Harm Tuenter). Those shelled hazelnuts can find their way through the oil industry or nougat factories for example. As well, if the customer asks for a variety in particular, another capital gain can be made due to the addition of specific work (pers. comm. Harm Tuenter). There is as well a small market for fresh in-shell hazelnuts (Germain and Sarraquigne, 2004). It is not very well-known; some advertisement would be needed, but it is worth trying because only France provides it (Mélon, 2016).

Hazelnuts produced in Belgium and The Netherlands can already find a wide range of buyers and customers: from all types of wholesalers (small or big, for organic products, for in-shell or shelled hazelnuts, for one specific variety) to direct selling at the farm and more recently also through ordering on the internet (pers. comm. Harm Tuenter). The difficulty is not to find buyers; indeed, producers in our regions attest that every year the demand is higher than the supply (pers. comm. Harm Tuenter). The difficulty is rather in predicting the production. As it can highly fluctuate (FAO, 2020), making fixed contracts can be really hazardous. It is therefore recommended to contact potential buyers only after the harvest and make agreements on what is available (pers. comm. Harm Tuenter). In any case, nut production is in general a market with no waste, thanks to the high demand on these products and their

long storage period (two years for in-shell hazelnut, six weeks for shelled hazelnuts and 14 days for roasted hazelnuts). If the access to bigger markets is the aim, supply has to exceed thousands of kilos. Making such a production in Belgium and The Netherlands can be easily reached as Dutch plantations have shown a yield of 4 000kg/ha (in-shell hazelnuts) (pers. comm. Ton Baltissen), making these orchards the most productive in the world; in comparison, Turkey only produces 800kg/ha on average, Italy produces 2 500kg/ha and the USA produce 2 100kg/ha (de Wit, 2014). These low yields in Turkey results from a combination of old and underproductive orchards, high density plantations, bad soil conditions and low management (Lundell et al., 2004).

Currently, the Wageningen University in The Netherlands is making some research hand in hand with the Ferrero Group because the country shows potential in developing hazelnut production. Moreover, Nazan et al. (2020) projected that hazelnut yield will decrease up to 13% in half Turkey's production areas by 2050 due to climate change, affecting the global hazelnut market. It is reasonable to think that big companies like Nestlé or Ferrero, relying a lot on Turkish hazelnuts, will look for alternative potential growing regions (IPD, 2014). Among those futur growing regions, agroforestry systems in Belgium and The Netherlands show a potential in hazelnut production.

Another point to underline: the transformation chain for large quantities of nuts is already in place in Northern Europe. Indeed, Rotterdam is the central pole where all types of nuts from all over the world arrive before being processed and distributed in Europe (pers. comm. Ton Baltissen).

Moreover, the costs for transportation will increase in the next few years, increasing the price of imported hazelnut at the same time (IPD, 2014). Local supply, with shorter distances between the different actors of the supply chain will be advantaged.

4.1. Side products

One kilogram of in-shell hazelnuts only provides 400 grams of edible kernels in average, the rest is shells. Recycling these shells and sell them as a side product can therefore become an interesting market. Shells are a valuable product in the energy industry due to their calorific value, ranging from 17.21 MJ. Kg^{-1} to 18.42 MJ. Kg^{-1} depending on the variety (Hebda et al., 2018). In comparison, oven-dry woody biomass has a calorific value of 18-20 MJ. Kg^{-1} (Huhtinen, 2006). Recent research has also shown the potential of lignocellulosic hazelnut shells to be converted into biofuels and other industrial products (Uyan et al., 2020).

Some other side products may be marketable too, like timber from the pruning that can be used for burning or for compost. It was formerly used in basketry, cooperage and manufactures of cane. As more craft works are brought up to date, supply of such products could become more popular in the years to come.

Edible mushrooms, such as *Tuber melanosporum* Vitt. and *Tuber brumale* Vitt., two types of truffles, grow naturally on hazelnut trees. A research about inoculation techniques on mature orchards have shown that between 28.6% and 45.2% of the inoculated trees got mycorrhizae of *Tuber melanosporum* one year after the inoculation. Trees that presented *Tuber brumale* mycorrhizae after one year are between 24.1% and 56.2% (Morcillo et al., 2007). This parallel activity can provide an added value to the original

hazelnut crop. Regarding mushroom culture, hazelnuts husks can also be used as an ingredient for substrate preparation for the cultivation of other mushrooms like shiitake (*Lentinula edodes* Berk.) (Peks, 2007).

Another source of income chose by some growers, is the sale of young plants after carrying out the propagation by themselves. Another example of income diversification is the production of other fruits or nut trees for a better profitability of their investment. The species should be chosen according to their harvesting periods. These periods should follow one another without overlapping to allow harvest and drying of one species at a time (Germain and Sarraquigne, 2004).

5. Difficulties and lock-ins of hazelnut production in Belgium and The Netherlands

Most nurseries have old varieties, 'Gunslebert' or 'Hall's Giant', and it is challenging to find newer varieties like 'Gustav Zeller' or 'Tonda di Giffoni'. Therefore, to obtain the varieties wanted, growers can decide to achieve the propagation on their own, through grafting, which allows fast multiplication of new hazelnut varieties (pers. comm. Harm Tuenter). In addition, nurseries don't have large stocks of young trees of all varieties, therefore it is important to make a reservation well in advance (a year at least) (pers. comm. Harm Tuenter).

Besides this, it is economically challenging to start a hazelnut production because there are a lot of starting costs: buying trees from nurseries, pruning tools, machinery to collect and process hazelnuts, and for some, the land. To try to keep those initial costs the lowest, extra manual work is needed or machinery could be hand-made. First incomes come only after at least four years. Hence, it is not viable as an only activity but can certainly be a good investment if it is started as a side activity. A plantation can have a good production for more than 30 years if a good management is applied to it. In the end, if the plantation has been well managed, it doesn't take much time during the year, around 150 hours/ha (pers. comm. Harm Tuenter). But first, it is crucial to make some research on the subject before starting a production (pers. comm. Harm Tuenter).

Another challenge that may prevent new farmers to begin with hazelnut production is the lack of a central structure, like a cooperative or a cooperation between different stakeholders. A place where hazelnuts can be shelled, processed, packed, and even dried. This type of structure can have disadvantages too if no clear agreements are made. For instance, during the years when the productivity is low and the prices are high, farmers would sell the nuts themselves but when the productivity is high, they would go to this central structure to get rid of the hazelnuts because the prices are so low. In that way, such a central structure can only be economically viable if clear agreements are made, e.g., on the obligation to deliver hazelnuts every year to the structure (pers. comm. Harm Tuenter).

Breeding programs are important to improve hazelnut plantation. Nowadays there are only two significant programs of varietal creation by hybridization: in Turkey (Hazelnut Research Institute, Giresun) and in USA (Corvallis University, Oregon) (Germain and Sarraquigne, 2004). This means that their development of new varieties is aligned with their production conditions and therefore doesn't meet Belgian and Dutch needs (Germain and Sarraquigne, 2004). In Belgium and The Netherlands, scientific researches only come from a trial implemented by Bob Wertheim in the early 90's and some results from

research in France; but these may not be significant as most of plantations are in the South of France, and therefore in a different climate. Nowadays, experiments on growing foreign varieties in Belgium and The Netherlands are solely based on farmers taking the risk to plant them (pers. comm. Ton Baltissen) and on the trial installed at ILVO.

5.1. Food Safety in Belgium

Regarding food security regulation by the Federal Agency for the Safety of the Food Chain (AFSCA or FAVV) in Belgium (2017), growers are responsible for the safety of the food they produce, manufacture and sell. Amateurs or professionals working in primary production must register within the Agency. Growers must apply good hygiene practices and be able to detect and control the potential dangers for food safety through self-control. In the case products may present a danger to the safety of the food chain, growers must notify the Agency (mandatory notification) and be able to trace their products. However, if the hazelnut plantation does not exceed 25 ares, no registration is required within the Agency.

6. Cultivating hazelnuts in an agroforestry context

Hazelnut trees are mainly planted in monoculture all over the world (Gönenç et al., 2006). If integrated into already existing arable crops, hazelnut trees, along with other nut and fruit trees, can be added on the edges of the crops, as alleyways between crop rows, or as hedges, without overlapping on productive crops (Dupraz and Liagre, 2011). These combinations provide benefits such as protecting adjacent waters against fertilizers and pesticides, limiting nutrients leaching, increasing biodiversity, reducing soil erosion and improving soil health (Dupraz and Liagre, 2011); making agroforestry systems more resilient to climate change than monoculture farms and allow a diversification of income (Doucet, 2019). If the trees are mixed with livestock, other benefits can be pointed out, such as improving animal welfare (Bracke et al., 2020), or providing organic manure thanks to animals grazing under the trees. Another important ecosystem service agroforestry offers, is the sequestration of CO_2 to help mitigate climate change (Hamon et al., 2009).

Farmers implementing agroforestry nowadays can receive some (financial) support for the instalment. Agroforestry systems can be eligible as Ecological Focus Area (EFA) hence meeting the requirements of the greening policies that Europe encourages through the first pillar of the CAP (Common Agricultural Policy). Moreover, agroforestry fits under Measure 8.2 of the 2nd Pillar of the CAP. Implementation of this measure is a choice to be made by the individual member states. In Flanders, this measure is implemented as an investment subsidy through which up to 80% of the planting cost (excluding VAT) can be granted (Flanders Department of Agriculture and Fisheries, 2020). Although providing a launching pad for farmers, subsidies can be risky too. Indeed, it has been shown in practice that it can lead to failure because farmers have counted too much on it or don’t pay enough attention for aftercare (pers. comm. Harm Tuenter). Hence, it is suggested to practitioners to ensure they first cover the costs of the business plan by themselves, after which the subsidy money comes as a bonus.

7. Characteristics of the hazelnut varieties planted at ILVO

Hazel trees (*Corylus* genus) belong to the Betulaceae family (Baldwin, 2015). Around 400 cultivars have been selected from wild populations (Mehlenbacher, 1991). "Yield and nut morphological, physical and chemical characteristics" (Cristofori, 2008) are highly related to the variety and to the environment and management practices (Cristofori, 2008). At the Research Institute for Agriculture, Fisheries and Food (ILVO), eight different varieties of hazelnut trees have been planted. Their characteristics are listed in table 2, from what is available in the literature.

Table 2 - Characteristics of the eight varieties in place at ILVO

			Tree		Hazelnut				Kernel		
Variety	**Country of origin**	**Other names**	**Vigour**	**Growth habit**	**Shape**	**Calibre (mm)**	**Weight (g)**	**Shell thickness (mm)**	**Shape**	**Calibre (mm)**	**Weight (g)**
Emoa 1											
Hall's Giant	France (3)	Merveille de Bollwiller, Hallesche Riesennus, Wonder von Bollwiller (4)	High (3) (6)	Medium (3) Large (6)	Round (3)	20 - 23 (4) 22-25 (6)	3.5-4.2 (4) 1.62 (2) 3-5 (6)	1.5 (4)	Ovoid (4) (6)	15-16 (4)	1.3-1.7 (4) 0.72 (2) 1.1-1.8 (6)
Corabel®	France (3)	Fercoril-Corabel® (3)	High (3)	Medium (3)	Round (3)	17.98+-3.91 (5)	3.39+-0.77 (5)	1.0+-0.08 (5)	Subspherical (4)	>16 (4)	1.6-2 (4)
Gunslebert	Germany (3)	Gunslegen, Gunslegener, Zellernuss (3)	High (3)	Upright (3) Large (6)	Long (3)	Large (3) 24-25 (6)	2.61 (2) 2-4 (6)				1.22 (2)
Kentish Cob	England (2)	Lange Spaanse, Longue d'Espagne (1) Lunga di Spagna (2), Lambert's Filbert (6), DuChilly (6)	Medium (6)	Large (6)	Long (6)		2.43 (2) 2-3 (6)		Oblong (6)		0.87 (2) 1.2-1.7 (6)
Gustav Zeller	Germany (3)										
Cosford	Great Britain (3)	Coxford (3)	High (3) (6)	Upright (3)	Long (3)	Large (3)	2-3 (6)		Oblong (6)		1.1-1.6 (6)
Tonda di Giffoni	Italy (3)		Medium (3)	Medium (3)	Round (3)	15.75+-0.96 (5)	3.04+-0.38 (5) 2.65 (2)	1.3+-0.57 (5)			1.17 (2)

Table 2 - Characteristics of the eight varieties in place at ILVO (suite)

	Kernel									
Variety	**Quality/Taste**	**Total oil (g/kg)**	**Pellicle removal**	**Cracking yield**	**Number of nuts per cluster**	**Husk**	**Productivity**	**Pollinating/main variety**	**Percentage of nuts attacked by the nut weevil**	**Percentage of empty nuts**
Emoa 1										
Hall's Giant	Firm, fragrant, sweet (4) (6)	587.37 (2)		36-41% (4) 44.38% (2) 36-43% (6)	1-2 (4) (6)	Removed easily during mechanical harvesting operations (4) (6)	Medium (4) (productive in continental area) (3) 0.97 T/ha (7)	Pollinating (4) Main (table and industry) (6)		0-5% (4) low (6)
Corabel®	Firm, fragrant (4)			43-48% (4)	2-3 (4)	Removed easily during mechanical harvesting operations (4)	Low (5), productive (3)	Main (table nut) (4) Pollinating (1)	+-9% (5)	25.7% (5)
Gunslebert	Sweet (1) less flavour (6)	600.32 (2)		46.24% (2) 42-49% (6)		Easily removed (1) fall without husk (6)	High (1)(3) 1.88 T/ha (7)	Main (table) (1) (6)	can be significant (6)	low but some years higher (6)
Kentish Cob		616.92 (2)	Hard (1) (6)	35.99% (2) 42-47% (6)	up to 5 (6)	Husks don't release the nuts (6)	Very high (6) 2.59 T/ha (7)	Pollinating (1) (6)	Moderate (6)	Moderate (6)
Gustav Zeller			Easy (1)				1.05 (8)	Main (table nut) (1)		
Cosford				52-60% (6)	2-4 (6)		Medium (3) 1.09 T/ha (7)	Pollinating (1)		Low (6)
Tonda di Giffoni	Firm, fragrant (4)	637.06 (2)		44-48% (4) 43.63% (2)	3-5 (4)	Removed easily during mechanical harvesting operations (4)	Medium (5)	Main (table and industry) (4)	+-3.7% (5)	+-14% (5)

(1) Pers. comm.
(2) Cristofori et al., 2008
(3) FAO, 2000
(4) Germain and Sarraquigne, 2004
(5) Solar and Stampar, 2011
(6) Wertheim and Goedegebure, 1988
(7) Wertheim and Goedegebure, 1988 (tonnes per hectare calculated with 1 111 trees/ha (4.5 m x 2 m))
(8) Wertheim and Goedegebure, 1988 (tonnes per hectare calculated with 807 trees/ha (4.5 m x 2.75 m))

The dissimilarities observed between the sources can be explained by distinct areas where the studies have been conducted. Wertheim and Goedegebure carried out their study in Zeeland and Flavoland, respectively in the South-West and North-West of The Netherlands, but it dates from 1988. More recently (2011), Cristofori et al. sampled hazelnuts in the Italian province of Viterbro. They underline that "The sensitivity of some […] cultivars […] to environment factors gives them a low adaptability and makes uncertain the success of their introduction in new areas." Therefore, an update of these data in the Dutch, and mostly in the Belgian, conditions is necessary to provide relevant information to future growers.

7.1. Limiting climatic factors

Hazelnut production requires particular weather conditions to ensure a good productivity. The limiting factors are rainfall, temperature, relative humidity and wind (Bergoughoux et al., 1978; Germain and Sarraquigne, 2004).

7.1.1. Rainfall

"Overall growth and production and future crop yields" depends on adequate soil moisture (Baldwin, 2015). Hazelnut trees need around 80 to 100 mm of water monthly from the end of April to the end of August (Germain and Sarraquigne, 2004). If irrigation is available, rainfall is not a limiting factor.

7.1.2. Temperature

i. Chilling temperatures

Chilling temperatures, expressed in hours below +7°C, are required to break the dormancy of catkins, female inflorescences and vegetative buds (Mehlenbacher, 1991, Germain and Sarraquigne, 2004).

ii. Spring frost

Reductions in productivity can be caused by spring/late frost at flowering (Bergoughoux et al., 1978). The critical value below which productivity decreases is around -3.5 to -4°C (Germain and Sarraquigne, 2004).

iii. Minimum temperatures

Temperatures below 21°C for a period of at least three days after the fertilization stops cell divisions of the future kernel, which results in the formation of empty hazelnuts (Germain and Sarraquigne, 2004).

7.1.3. Relative humidity

Ideal relative humidity levels are 70-80% (Bergoughoux et al., 1978). Indeed, the poorly developed root system of the hazel trees does not allow enough water to be drawn, even with irrigation, to compensate for high evapotranspiration when the air is dry (Germain and Sarraquigne, 2004).

7.1.4. Wind

Hazelnut are wind-pollinated (anemophilous). However, at a distance of more than 15-20 m from their emission point, their concentration decreases rapidly (Germain and Sarraquigne, 2004). Hence, places that are too windy are not recommended. Northern and Eastern cold winds can also be detrimental to flowering (Wertheim and Goedegebure, 1988). Moreover, dry days in winter are required to allow pollens to be dispersed through the air by light winds (Baldwin, 2015). Strong winds coupled to low humidity and high temperature causes also moisture deficit, inducing reduction in growth and nut development (Baldwin, 2015).

Section II

ARTICLE

I. Introduction

A sustainable agriculture is more than ever needed to help mitigate and adapt to climate changes we are facing today (Thissen, 2019). As the FAO (2020) reports, the rate of deforestation between 2015 and 2020 was estimated at 10 million hectares per year. The main driver of this deforestation remains the same: agricultural expansion (FAO, 2020). As world's population has increased sharply over the past century, intensifying traditional agricultural systems to meet these increasing food needs has usually been the chosen strategy (Nair, 1988). But this type of agriculture has often undesirable environmental or ecological consequences, such as soil erosion, salinity, waterlogging and the contamination of aquifers with chemicals (Nair, 1988). This rapid depletion of forest resources and agricultural sustainability could be impacted significantly through agroforestry practices (Nair, 1988).

A commonly accepted definition of agroforestry, given by Van Noordwijk in 2019, describes this land-use systems/practices as "a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land management unit as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence. In agroforestry systems, there are both ecological and economic interactions between the different components". Agroforestry has therefore been divided in different subcategorized systems depending on which component is involved: silvopastoral (livestock and woody perennials), silvoarable (arable crops and woody perennials) and agrosilvopastoral (livestock, arable crops and woody perennials) (Augère-Granier, 2020).

Changing agriculture however goes hand in hand with changing the consumer behaviour and diet (Poux and Aubert, 2018). Indeed, according to the World Health Organization, food-related diseases are on the rise (diabetes, obesity, cardiovascular diseases), Europeans' eating habits are neither healthy nor sustainable. In that context, a more plant-based diet is promoted as part of the change needed in our agriculture. Especially as diets made of grains, dried fruits, vegetables and seasonal fruits generally have a lower carbon footprint than those with a high meat content (IPCC, 2019).

Simultaneously, the Consortium Agroforestry Flanders led by Flanders Research Institute for Agriculture, Fisheries and Food (ILVO) Belgium noticed a growing interest in planting hazel trees in an agroforestry context. Indeed, agroforestry offers different advantages when well-managed. The reduction of risks through income diversification and a higher productivity (Doucet, 2019) thanks to facilitation processes due to the modification of the environment of one species by another one (Dupraz and Liagre, 2011).

To this day, Turkey remains the world's leader in hazelnut production by producing nearly 70% of the world production (FAO, 2020) but their production faces various issues putting it on a knife-edge and threatening the environment. As three quarters of the world importation in Europe are for Germany, Italy, France, Holland, Belgium, Austria and Switzerland (Germain and Sarraquigne, 2004), new spots of sustainable and local production of high-quality hazelnuts are therefore needed in these regions to meet the society's high standards.

The purpose of this study is to examine the potential of hazelnut production in an agroforestry context in Belgium and the Netherlands through a long-term variety trial of hazelnut trees in Flanders and the implementation of semi-structured interviews. For this, we focus upon three main research questions:

(1) what is the impact of tree variety choice, mixed cropping systems and other agronomic & management parameters on hazelnut tree productivity as well as on nut quality and taste, (2) what is the current status of hazelnut production and processing in this region, and (3) what future production, processing and marketing opportunities exist for hazelnut in this region.

II. Material & Methods

1. Experimental site location and historic

The experimental site is in Merelbeke (Figure 2 (a)), East Flanders, Belgium (50°97'56''45'''N, 3°77'77"65"'E; 25 m alt.). This is a is a long-term silvopastoral experimental trial implemented by the Research Institute for Agriculture, Fisheries and Food (ILVO), where interactions between tree growth and development, soil conditions and presence, productivity and welfare of free-range chickens is being assessed. Initially, in April 2013, a plot experiment was installed with two contrasting vegetation types: short rotation coppice (SRC) of willow (*Salix* sp.) and grassland. Since 2014, different trials with broilers and laying hens have been performed here. In a second stage, in February 2017, young hazelnut trees (*Corylus avellana L.*) of different varieties have been planted on the original grassland plots. The objective of this hazelnut trial is not only to assess interactions between chickens and the two types of vegetation (open hazelnuts orchard and dense SRC willows) but specifically also to assess and compare productivity of the different varieties of hazelnut. In this thesis, we focus specifically on the hazelnut variety trial, but interactions with chicken presence and the two SRC willows plots are taken into account as well.

The climate in Belgium is defined as a Cfb (temperate oceanic climate) in the Köppen-Geiger classification system. The mean annual precipitation and temperature are about 805 mm and 9,7 °C respectively (IRM data).

(a) 

(b) 

Figure 2 - Location of Merelbeke in Belgium, (b) aerial image of the experimental trial with the study plots A and D, and the chicken free areas in green.

Figure 2 (b) shows an aerial image of the four plots (A, B, C and D) constituting the trial. Willows cover plots B and C and hazel tree on plots A and D. The green rectangles are fenced, chicken free references areas. Since the installation of the hazel trees, three rounds of chicken trials with laying hens took place, with each time four groups of chicken (*Gallus gallus domesticus* L.).

1.1. Cultivars of hazel trees on the trial

The following eight different cultivars of hazel tree (*Corylus avellana L.*) were selected: 'Emoa 1', Hall's Giant', 'Corabel', 'Gunslebert', 'Kentish Cob', 'Gustav Zeller', 'Cosford' and 'Tonda di Giffoni'.

The labelling of each tree follows the "Plant code" listed in table 3, preceded by A or D (plot) and followed-up by a single number from 1 to 168, forming all together a unique code, specific to each tree and containing all the information about it. Upon installation of the trial, 21 trees of each variety were planted.

Table 3 - Plant code defining intrinsic characteristics of each variety

Plant code	First character of 'Plant code'	Second character of 'Plant code'	Third character of 'Plant code'	Variety	Pruning management associated to the variety at plantation
	Code for variety	Age at planting	Root (w) - Graft (e)		
A2w	A	2	w	Emoa 1	Gobelet
B2w	B	2	w	Halle's Giant	Shrub
C1w	C	1	w	Corabel	Gobelet
C2e	C	2	e		
D2w	D	2	w	Gunslebert	Gobelet
E2w	E	2	w	Kentish Cob	Shrub
F1w	F	1	w	Gustav Zeller	Gobelet
F2e	F	2	e		
G2w	G	2	w	Cosford	Shrub
H2w	H	2	w	Tonda di Giffoni	Gobelet

Trees are distributed on plots A and D according to the plan in Annex 1. The distance in between the trees is 7,5m x 3m.

In the table 3 above, 'root' and 'graft' are variables referring to two types of vegetative reproduction of the trees. The former is a result of layering (Figure 3 (a)) and the latter is achieved through grafting (Figure 3 (b)). In this trial, the rootstocks for grafting come from the variety 'Gunslebert' as it provides the least root suckers.

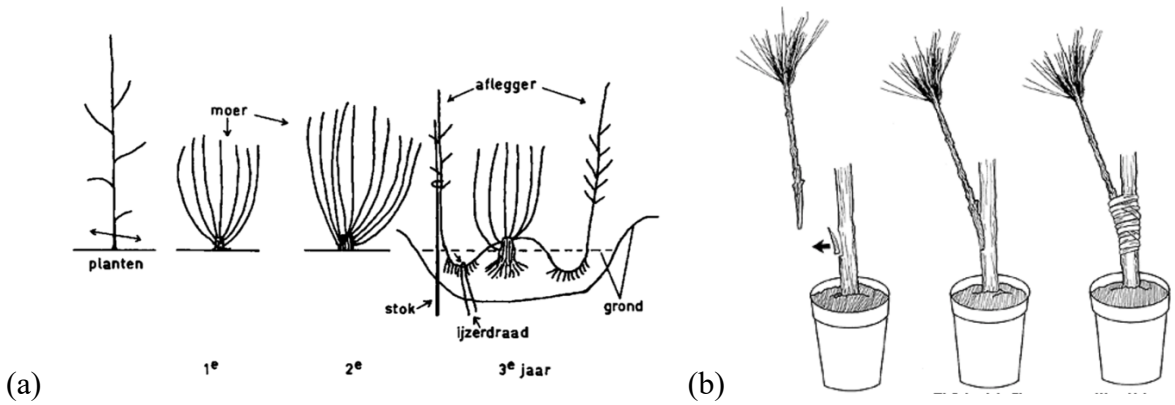


Figure 3 – (a) layering: development of plants by rhizogenesis (root development) on an aerial part of a mother plant (source: Wertheim and Goedegebure, 1988) and (b) grafting: development of plants by implanting in the tissues of a plant (the rootstock) a fragment (the graft) of another plant or the same plant (source: "Grafting", 2020)

For only two varieties, 'Corabel' and 'Gustav Zeller', plants from the two types of vegetative reproduction were planted. As shown in table 3, this variable is linked to the age at plantation as follows:

- One year old and 'root'
- Two years old and 'graft'

All the other varieties were two years old at the time of plantation and 'root'. This arrangement prevents to differentiate the effect of 'age' or 'reproduction" on the productivity in further statistical analysis.

Hazel trees naturally grow in a shrub shape. The pruning management 'shrub' therefore allows the tree to grow freely, except for excess suckers that are removed annually (Germain and Sarraquigne, 2004). The 'Gobelet' (Figure 4) management on the other hand has three or four radiating carpenters at 60-80 cm from the ground (Germain and Sarraquigne, 2004).

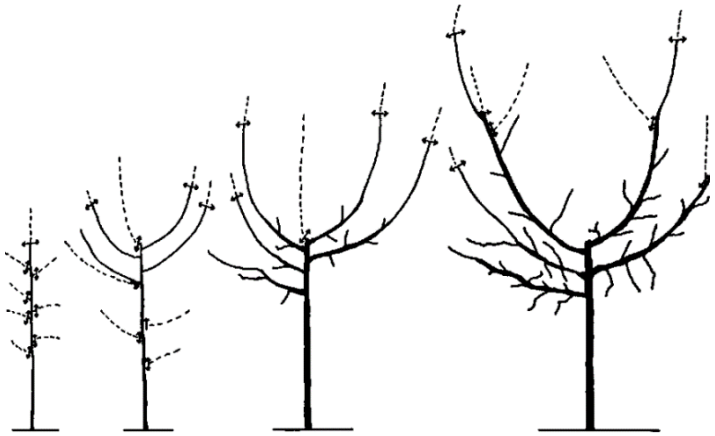


Figure 4 – 'Gobelet' pruning management type (source: Wertheim and Goedegebure, 1988)

The experimental arrangement at plantation wasn't completely random but was designed in such a way that every variety can be found all over the area. To assure that each variety is statistically equally distant to the chicken stables, the distances of each tree to the two different locations of the chicken stables was calculated using the Pythagorean theorem. Then, the mean distance of each variety to the two chicken stables was calculated. The pairwise comparisons of the mean distances reveals that no distance differed significantly of each other (p-value=0.99 and p-value=1), meaning that each variety was equally distant to the two different locations of the chicken stables.

1.2. Description of chicken trials

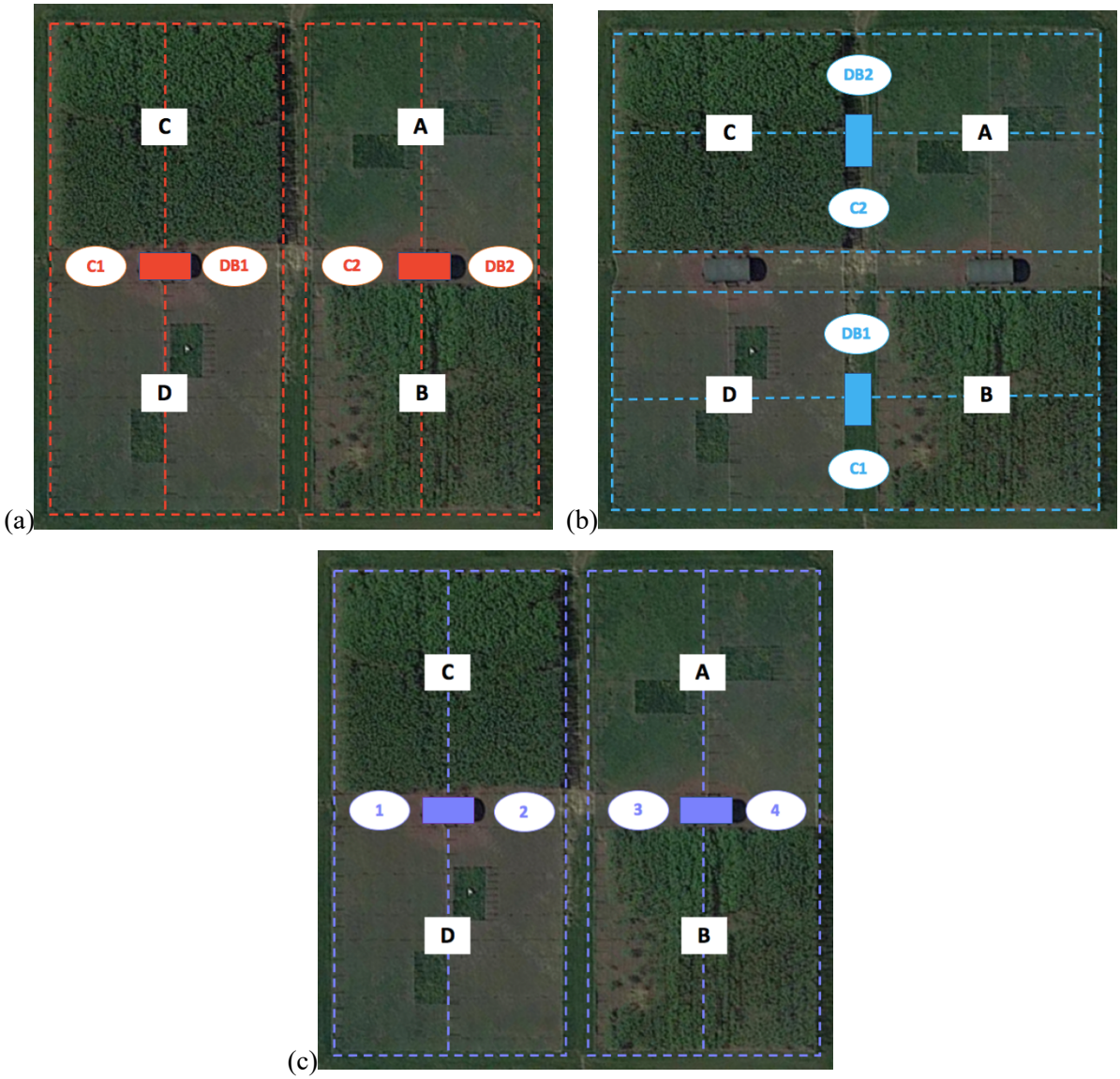


Figure 5 - Disposition of chicken rounds: (a) round 1, (b) round 2 and (c) round 3: the dotted lines represent the chicken groups, the colored boxes represent the mobile chicken stables (each group occupies half the stable).

There have been three rounds of chicken trial. At every new round, new chicken groups have been raised and the mobile chicken stables have changed position to reduce local accumulation of nutrients. The first round (Figure 5 (a)) of the chicken experiment took place from 04/09/2017 to 19/07/2018 (318 days),

with 51 chickens on each group. The second round (Figure 5 (b)) took place from 28/09/2018 to 29/09/2019 (367 days) with 49 chickens in each group. During this second round, two fox attacks took place. The first attack on 12/02/2019 killed 10 chickens on plot DB2, the second attack on 28/04/2019 killed 11 chickens on plot DB1 and 32 chickens on plot C1. The third round (Figure 5 (c)), with 50 chickens in each group, started on 23/06/2020 and will finish in May 2021. The dotted lines represent the chicken groups, the colored boxes represent the chicken stables (each group occupies half the stable).

2. Measurements

The first significant harvest occurred in the autumn of 2019. In that season, all the hazelnuts were collected at once, directly on the trees. The data taken into account were the total number of hazelnuts, the ease of loosening from the husk, which surrounds the hazelnut, the total fresh weight, the size class of the hazelnut, the main color of the hazelnuts harvested, the number of empty and full hazelnuts from a subsample, the weight of fresh/dry kernels and shells of the full hazelnuts.

For the 2020 harvest, the hazelnuts were collected after falling from the trees and over a longer period of time, in order to understand how hazelnuts fall naturally over time. The 2020 protocol covered a wider range of settings. In addition to the parameters mentioned above, a more detailed classification of hazelnuts and kernels was followed over the weeks of harvest. Thus, the number of green, brown, aborted and shriveled hazelnuts, the number of hazelnuts fallen with their husk, the number of hazelnuts damaged by insects or other animals, the number of shriveled/aborted, twin and rotten kernels was reported. Besides, the field was screened to update the overall health of the trees by visually evaluation of the leaves and trunk health.

2.1. Leaf Scores

Leaf color can run from pale yellow to dark green, depending on the cultivar. The color of the leaf may apply to the nitrogen status of the tree. The discolorations of tissues between the veins refers to Mn and Mg deficiency. In terms of damages, there may be leaf damage such as sun burn scorches or leaf margin damage in case of K deficiency. In both cases, the damages appear brown. The following scores were created with the help of Bob Wertheim, a former researcher of fruit and nuts cultivation of the Wilhelminadorp Test Station and adviser of the Nederlandse Notenvereniging (Dutch Nut Association).

The ‘Leaf Damage Score’ as the percentage of damaged leaves due to sunburn scorchers or K deficiency (pers. comm. Bob Wertheim) (1 = <1%, 2 = 1-25%, 3 = 25-50%, 4 = 50-75%, 5 = >75%) (Figure 6 (a)). In parallel, the intensity of this damage was recorded, varying from low, moderate to strong damage (Figure 6 (b)).

(a)  (b) 

Figure 6 – (a) Tree with >75% damaged leaves and (b), strong intensity damage on a leaf.

2.2. Pruning management

The pruning management of the trees is associated to the cultivar (shrub/Gobelet) at plantation. No pruning occurred during autumn/winter '19- '20; some 'Gobelet' trees therefore grew more freely and got closer to a 'shrub' shape. For this study, the data about this factor was updated in order to show a potential effect of the tree shape management on the hazelnut production.

2.3. Presence of chicken

Local accumulation of chicken manure can lead to high concentrations of mineral nitrogen and phosphorus in the soil if the range-use is not homogeneous (Bracke et al., 2020) and previous research on this trial pointed out that the chickens were most often seen near the chicken stables (Bracke et al., 2020).

Knowing that the chickens don't use their free-range homogeneously leads to a potential fertility gradient on the field, with presumably higher concentrations of nutrients close to the stables. To reflect this gradient and integrate it in further statistical analysis, an index characterizing the chicken pressure for each tree (intensity *i*) was calculated. It was built by combining two weighted means (Formula 3). The weighted mean number of chickens $\overline{n}$ is the number of chickens divided by the number of days the chickens were on the field (Formula 1) and the weighted mean distance $\overline{m}$ is the distance of each tree to the chicken stable divided by the number of days the chicken stable stayed at that position (Formula 2).

Formula 1 : $\bar{n} = \frac{\sum n.d}{\sum d}$,

with *n*, the number of chickens and *d*, the number of days the chickens stayed on the field.

Formula 2 : $\bar{m} = \frac{\sum m.d}{\sum d}$,

with *m*, the distance (in meters) of each tree to the chicken stable and *d*, the number of days the stable stayed on the field.

Formula 3 : $i = \frac{\bar{n}}{\bar{m}}$,

With *i*, the intensity of chicken pressure on each tree. Therefore, if the weighted distance is high and the weighted number of chickens is low, the intensity is low. And inversely, if the weighted distance is low and the weighted number of chickens is high, the intensity is high. If both weighted means are either high or low, the intensity will be in between the two "extremes". This intensity parameter allows to take into account the loss of chickens in different parts of the trial due to the two fox attacks.

2.4. Update of tree damages

In 2019, five trees (6, 8, 51, 57 and 138) had to be re-planted. Those trees are one year younger than the others and are therefore not taken into account in the statistical analysis. Any other damages that have occurred during the period from 2019 to 2020 were recorded.

2.5. Harvest

From mid-July, the field was screened daily to detect when hazelnuts started falling. From that moment on, fallen hazelnuts were collected per individual tree. To avoid losses due to rodents or birds feeding from the hazelnuts, harvest was planned four times a week. The weekly harvest was stored in individually numbered container per tree, allowing the hazelnuts to dry in the open air in a greenhouse.

On a weekly basis, the data representing the total harvest of the week was reported. It concerned, for each tree:

- Number of hazelnuts harvested
- Number of green and brown hazelnuts
- Number of aborted and shriveled hazelnuts
- Number of hazelnuts eaten by insects or animals
- Number of hazelnuts fallen with their husk and the difficulty to remove it (Table 4)
- Total weight of hazelnuts

Table 4 – Description of the difficulty score to remove the husk

Difficulty Score	Description
0	The husk is removed just by shaking
1	The husk comes off quite easily by hand
2	Hard but the husk comes off completely
3	Hard and the bottom of the husk remains stuck to the nut

Then, a random subsample, around 30% of the total number of hazelnuts was taken. After cracking, these parameters were reported: number of filled, empty, aborted, twin and rotten hazelnuts

Moreover, the data concerning the weight of the kernels and the weight of the shells using only the "filled hazelnuts" category was detailed.

After all the weekly data was collected, the intact hazelnuts were put in a jute bag by variety.

3. Animal survey

Two types of animal damages were recorded on the field.

- A small hole (Figure 7 (a)) left by hazelnut weevil larvae (*Curculio nucum* L.) (Figure 7 (b)) when leaving the hazelnut. It is the main pest of hazel trees (Piskornik, 1989), the larvae feed on the kernel, making it inedible.
- Bite marks left by rodents (Figure 7 (c)).

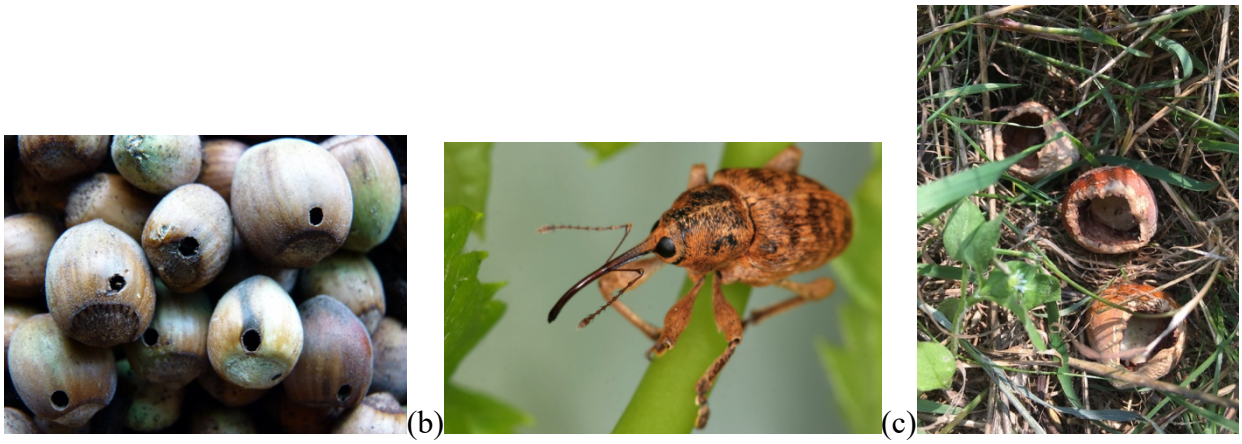


Figure 7 – (a) Exit hole made by hazelnut weevil larvae (source: "*Curculio nucum*", 2020), (b) hazelnut weevil (source: "*Curculio nucum*", 2020) and (c), bite marks by rodents.

Camera traps were installed on the field to capture the animal species visiting the trial and eating hazelnuts on the ground. Height cameras were set on the field, focusing either on the crown for birds or

on the ground for rodents. To assess bird presence, trees with a big and open crown and a large number of hazelnuts, where birds can easily land, were chosen to place a camera in front of it. For rodent record, the cameras were placed next to rodent holes, focusing on the foot of one tree where some hazelnuts were left on the ground. The number of hazelnuts left on the field for this survey was added to the weekly data.

To know which hazelnut varieties are the most preferred by predators, five hazelnuts of each variety were placed on the ground in front of a camera trap after harvesting period (Figure 8).

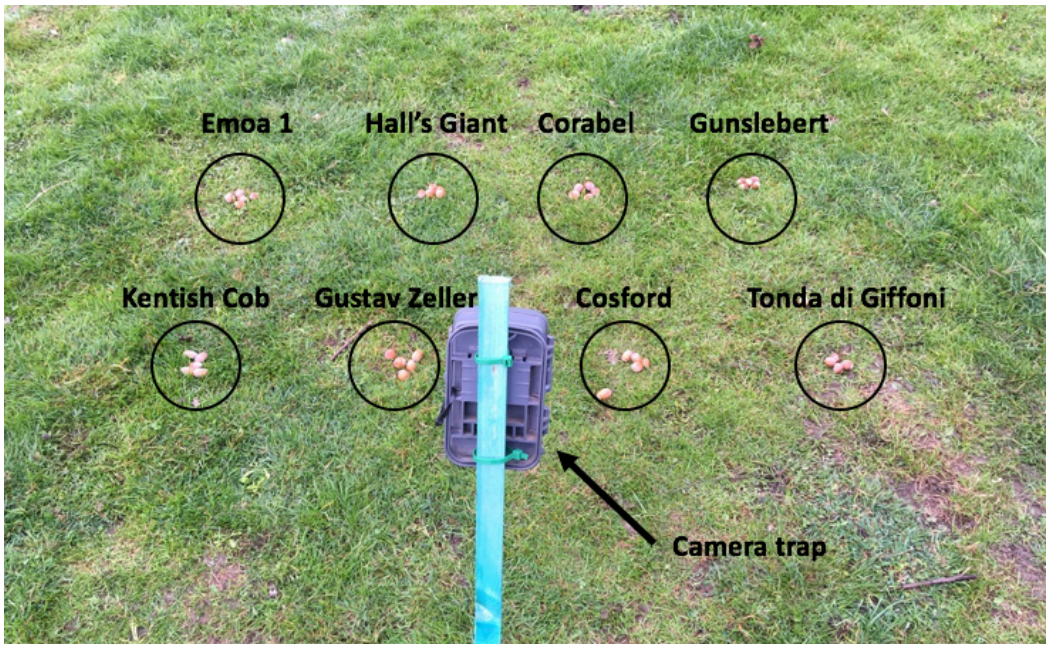


Figure 8 – Disposition of hazelnut varieties on the ground.

4. Hazelnut processing

A next step after harvesting the hazelnuts was to process them into a consumable product. In this study particularly, the hazelnuts needed to be prepared for a taste trial. For this, the hazelnuts needed to be washed to remove dirt and any possible infectious agents. After cracking, four samples have been subject to microbiological tests for further investigation on those possible infectious agents. Finally, half of the total harvested hazelnuts were roasted in order to have two variants for each hazelnut variety.

4.1. Washing

The organization of a taste trial on these hazelnuts involves a serious responsibility to ensure a safe product for consumption (Wells, 2013). As the hazelnuts have been collected on the ground where organic chickens run free, there is a risk of contamination by osmophilic yeasts and xerophilic fungi, *Escherichia coli*, *Bacillus cereus*, Salmonella and *Listeria monocytogenes* (information received by Koen De Reu, ILVO). In an attempt to remove those yeasts, fungi, *E. coli* and dirt, the hazelnuts were washed under water at 70°C for 60 seconds. After washing, the hazelnuts were left to dry overnight on large superimposed grids, not overlaying.

4.2. Size sorting and cracking

For each variety, the hazelnuts were sorted by size (14mm, 16mm, 18mm, 22mm, 24mm and 26mm diameter) using calibration sieves (Figure 9 (a)) from Feucht-Obsttechnik. Each size group of hazelnuts was cracked separately using the Walnut and Hazelnut hand cracker "WAL MAN" (Figure 9 (b)) from Feucht-Obsttechnik, after its size was adjusted. The kernels were separated from the shells by hand and kept in a container by variety.

(a)  (b) 

Figure 9 – (a) Calibration sieves and (b) hand cracker "WAL MAN" from Feucht-Obsttechnik.

4.3. Roasting and pellicle removal

Roasting is a thermal process at temperature above 125°C to create typical specific roast flavor, brown color and crunchy texture (Perren and Escher, 2013). Each variety was placed on a large grid with kernels in one layer and baked for 20 min at 150°C and stirred twice in between.

To remove the brown pellicle and evaluate the degree of pellicle removal, hazelnuts were rubbed in a kitchen towel for 30 seconds and then in another one for 15 more. The final result is visible on figure 10.

Figure 10 – Removing of the brown pellicle.

Then, a classification, with respect to the scale made by Bob Wertheim, of each variety was made (Table 5).

Table 5 - Degree of pellicle removal

Score	Description
1	No kernel blank
3	Few blanks
5	Moderate number
7	Mainly blank
9	All blank

The high content of unsaturated fatty acids in nuts makes them susceptible to excessive oxidation by heat, light and oxygen (Perren and Escher, 2013). The moisture removal during roasting doesn't increase the product stability of the nuts (Perren and Escher, 2013). To avoid quality deterioration like rancidity and off-flavor formation, but also to avoid a loss of nutrients and toxicity (Shahidi and John, 2013) during storage, roasted hazelnuts must be vacuum packed (Perren and Escher, 2013) and stored in a dark storage room at 20°C and a relative humidity of 55%.

5. Taste panel

5.1. Ethical Commission

The taste panel (sensory test) took place at the Food Pilot of ILVO under the supervision of Barbara Duquenne. A first step was to go through an internal Ethical Commission. The application provides more information about the project, the samples and the trial design of the sensory test. On the basis of these information, it is decided whether the application should go through the ECSG or not.

Furthermore, the sensory test can only be approved under the condition that no molds grow on the nuts. As the hazelnuts were only washed with water at 70°C (see 4.1. Washing), some microbiological analyses were recommended to ensure that there are no microbiological risks associated with the taste trial. The tests were limited to *E. coli* (hygiene indicator), yeasts and fungi (no osmophilic or xerophilic because the activity of water is too low for their growth). Salmonella is killed by heating and *Listeria monocytogenes* and *Bacillus cereus* won't grow due to low water activity.

Only the varieties 'Hall's Giant', 'Gunslebert', 'Kentish Cob' and 'Tonda di Giffoni' have been subject to these microbiological tests. Ten grams of each sample was subsampled and analyzed. After making appropriate dilutions in Maximum Recovery Diluent (MRD; Oxoid, Basingstoke, United Kingdom), the following microbiological enumerations were performed: *E. coli* and yeast and molds corresponding the AFNOR BRD-07/01-07/93 protocol and ISO 7954 (1987) standard respectively. For *E. coli* enumerations, samples were plated on RAPID' *E. coli* 2 Agar (Bio Rad) and incubated at 44°C for 24 hours. Oxytetracycline-Glucose-yeast extract agar (OGYE; Oxoid) was used for yeast and mold enumerations and incubated at 25°C for five days.

5.2. Humidity content

Humidity content is directly linked to texture (pers. comm. Bart Van Droogenbroeck). Humidity content was measured by drying pre-smashed hazelnuts in a moisture analyzer (model HC103 (230V) from Mettler Toledo) at 105°C until reaching constant weight. The humidity content calculated is the result of the difference of the weight before and after drying, divided by the fresh weight.

5.3. Flavor test

In order to better understand the differences in taste and therefore be more able to meet industry and consumers requirements, a taste trial was conducted at the Food Pilot of ILVO. The taste trial covered the eight varieties growing at ILVO plus one from a commercial source for reference. The taste trial took place for two days with 30 people each day. On Tuesday 24/11/2020, panelists tasted the naturally dried hazelnuts and on Thursday 26/11/2020, panelists tasted the same hazelnuts but roasted. The panelists had to rank the samples according to preference. At the end, they had to shortly describe why they chose their favorite and least favorite variety. This taste study was conducted in the sensory lab equipped according to ISO 8589:2007 and with the help of the FIZZ software. The statistical test used by this software to statistically analyze the sensory test results is the Friedman test, a non-parametric statistical test. It is used

to detect if a variety is constantly ranked higher or lower than the other varieties across multiple test attempts (FIZZ by Biosystems, n.d.).

6. Statistical analysis

All the results were statistically processed using RStudio® software (version 1.3.1073) and Excel (Microsoft Office). The production (total weigh of hazelnuts in-shell) was analyzed with a Linear Mixed-Effects model (LMM) (function “lmer”, R-package “lme4”) (Bates et al., 2015) to evaluate the effect of fixed variables. Moreover, each relevant interaction between variables of the statistical model explaning productivity was analyzed separately.

III. Results

1. Productivity

1.1. Overall changes in productivity over time

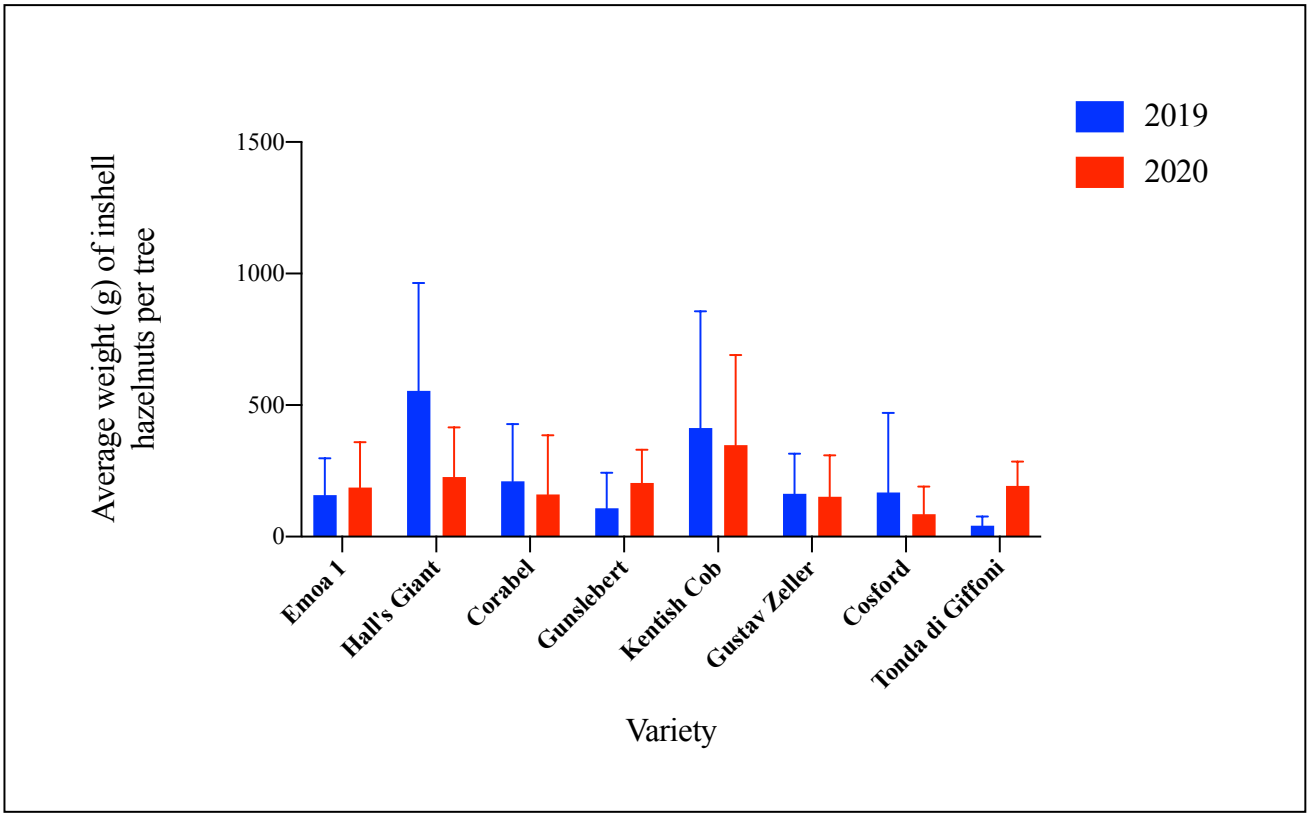


Figure 11 - Difference in production between 2019 and 2020 of average weight (g) of hazelnuts produced by variety.

As attested by the figure 11 above, three varieties (‘Gunslebert’, ‘Tonda di Giffoni’ and ‘Emoa 1’) have shown an increase in production. ‘Kentish Cob ’ and ‘Gustav Zeller’ have shown no meaningful change in production over the two years, whereas ‘Corabel’, ‘Cosford’ and especially ‘Hall’s Giant’ were faced with a decrease in production.

These two annual harvests have also been confronted in a Linear Mixed-Effects model, with only the variety, the date and the random effect ‘plot’ as variables, but the variable ‘date’ didn’t turn out to be significant (p-value=0.2418). In the following points, the description of the productivity is only analyzed using the harvest of 2020.

1.2. Description of the productivity

The different fixed factors used to build the model were: varieties (‘variety’), pruning management (‘management’) and intensity of chicken pressure (‘intensity’); and one random effect: plots (‘plot’).

Depending on the order the factors were added, the significance changed. The factors 'variety' and 'intensity' were always highly significant (p-value<0.05) but the factor 'management', if added at first, had a p-value of 0.03834 and if added at last, a p-value of 0.3501. In order to know if the factor 'management' had to be included in the model or not, the model with all the factors was compared to three similar models, in which one variable was removed at a time. It resulted the variable 'management' was not significant either. Thus, the only fixed variables chosen to explain differences in productivity were 'variety' and 'intensity'. Also, possible interaction between the factors was analyzed but the interaction 'intensity' – 'variety' wasn't significant (p-value=0.1683).

The results of the update of the pruning management, described in point 2.2. of the Material & Methods, are described in table 6.

Table 6 – Number of trees managed as 'Gobelet' or 'Shrub' per variety

Variety	Gobelet	Shrub	No tree
Emoa 1	14	7	
Halle's Giant		21	
Corabel	15	5	1
Gunslebert	17	3	1
Kentish Cob		21	
Gustav Zeller	16	3	2
Cosford		21	
Tonda di Giffoni	18	2	1

The results of the model are presented in table 7 in average grams of hazelnut per tree per variety for a minimal intensity of 1.0374 (lowest intensity possible on this trial, the highest intensity possible is 5.3277). The most productive varieties in terms of total weight of hazelnuts are 'Kentish Cob', 'Hall's Giant', 'Gunslebert', 'Tonda di Giffoni' and 'Emoa 1'; the least productive varieties are 'Cosford', 'Gustav Zeller' and 'Corabel'.

The effect of the plot has been analyzed in a Generalized Linear Model but this variable wasn't significant (0.2559) meaning that there is no influence of the SRC willow plots on the hazelnut plots.

Table 7 - Mean and standard error of the model showing the average production (in grams) of a tree depending on the variety and for an intensity (*i*) of 1.0374 and 5,3277

Variety	*i*=1.0374		*i*=5.3277	
	Mean	Std. Error	Mean	Std. Error
Emoa 1[ab]	127.415	50.347	376.852	50.618
Hall's Giant[b]	157.925	76.006	407.362	76.007
Corabel[ab]	107.365	76.51	356.802	76.51
Gunslebert[b]	141.585	76.547	391.022	76.547
Kentish Cob[b]	299.925	76.525	549.362	76.525
Gustav Zeller[ab]	88.285	77.144	337.722	77.144
Cosford[a]	8.685	78.709	258.122	78.709
Tonda di Giffoni[b]	139.765	76.51	389.202	76.51

a,b value with a different letter in the same column per test significantly differ ($p<0,05$)

1.3. Time distributions

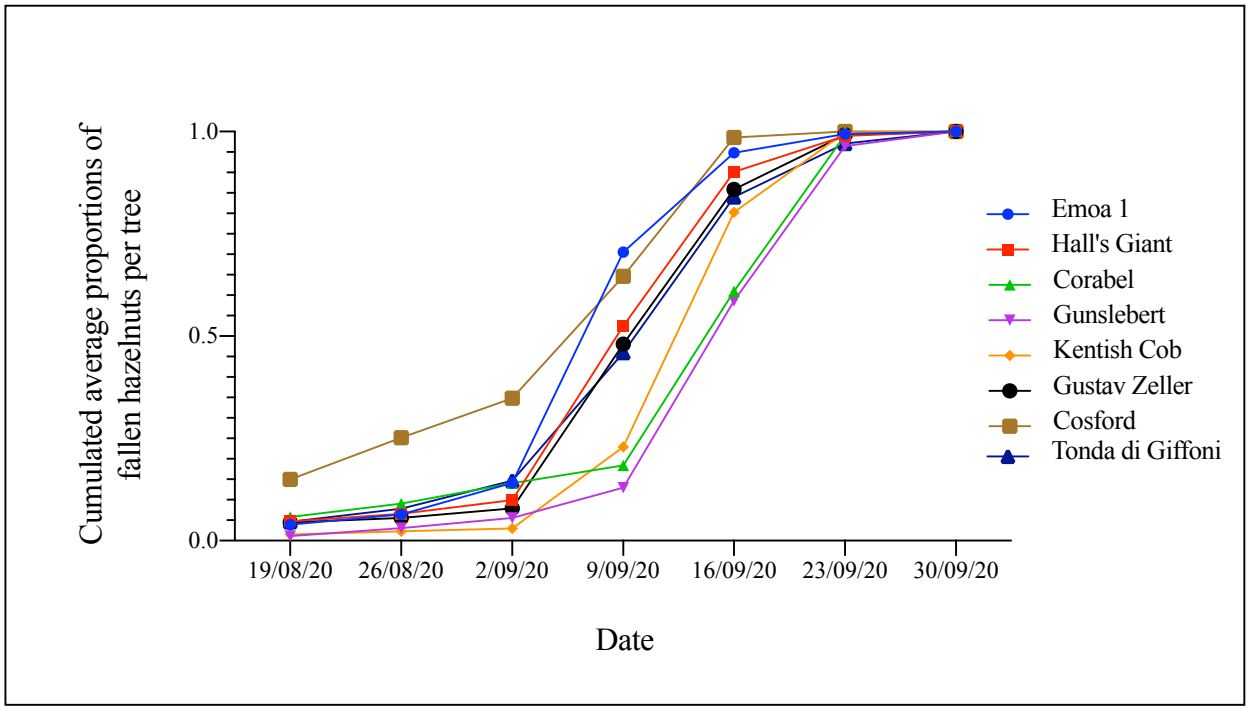


Figure 12 - Cumulated average proportions of hazelnuts fallen per tree over time by variety.

The figure 12 shows the cumulated average proportions of hazelnuts that have fallen per tree on each of the seven dates of harvest. The nut fall of all varieties began around the same time (19/08/2020). At that time, around 5% of all nuts had already fallen per variety. This was similar for all varieties. After three weeks, varieties 'Emoa 1', 'Hall's Giant', 'Kentish Cob', 'Gustav Zeller' and 'Tonda di Giffoni' lost around 12% of hazelnuts each. For varieties 'Corabel' and 'Gunslebert', they lost around 16% but after four weeks. Once these periods of time passed, the varieties 'Emoa 1', 'Hall's Giant', 'Corabel' and

‘Gunslebert’ lost around 80% of their hazelnuts within two weeks. ‘Kentish Cob’, ‘Gustav Zeller’ and ‘Tonda di Giffoni’ lost around 90% of their hazelnuts over three weeks. The fall of ‘Cosford’ hazelnuts was more uniformly spread over the harvesting period.

Figure 13 shows the percentage of empty hazelnuts for each of the seven harvesting moments for each variety. As expected, this percentage was high in the beginning and then decreased. Efficient harvesting started when less than 50% of the hazelnuts are empty. For varieties ‘Emoa 1’ and ‘Tonda di Giffoni’ it started in the third week after the first hazelnuts started falling; and lasted for three weeks before this percentage of empty hazelnuts reached the 50% threshold again. For all the other varieties, it started one week later, during the fourth week and lasted for two weeks; which means the end of efficient harvesting happened at the same time for all the varieties, around six weeks after the first falls of hazelnuts. If the correlation is made with the figure 12, it can be note that when the trees were loosing small amount of hazelnuts, typically during the first three weeks and the last week, the proportion of empty hazelnuts were high.

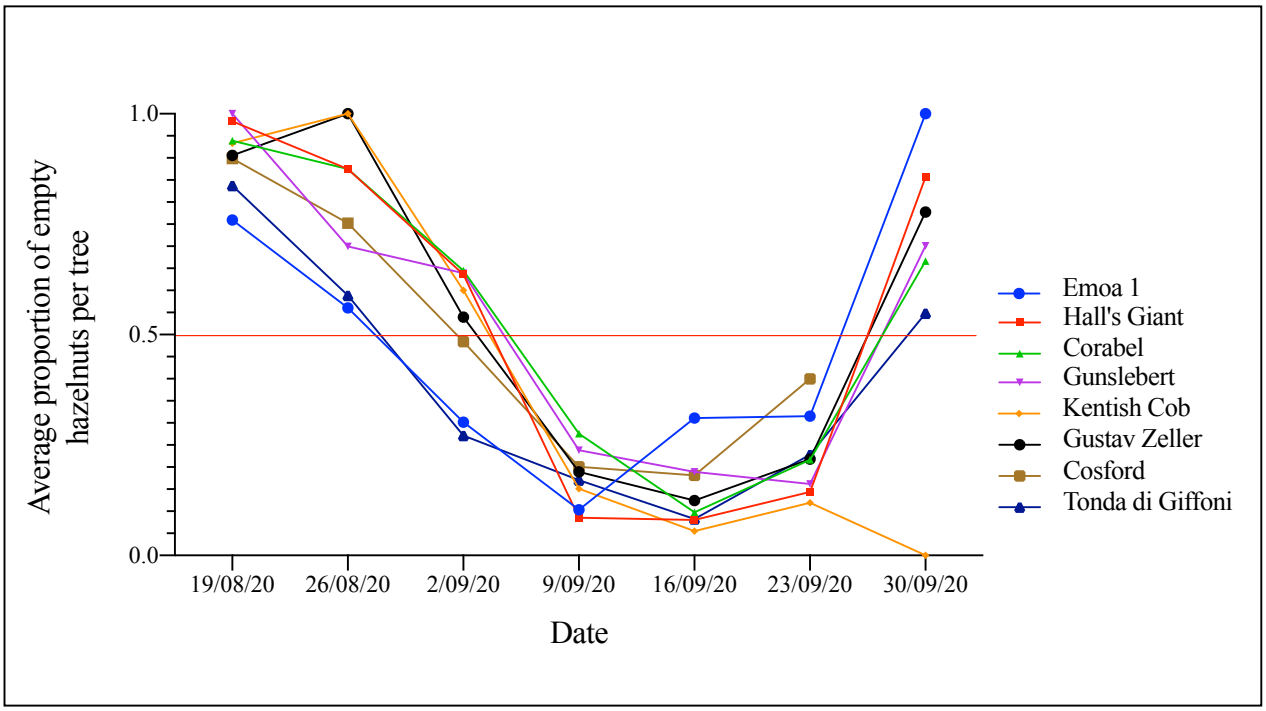


Figure 13 - Proportions of empty fallen hazelnuts over the seven dates of harvest, by variety. The red line at 0.5 represents the efficient harvesting treshold.

1.4. Husk

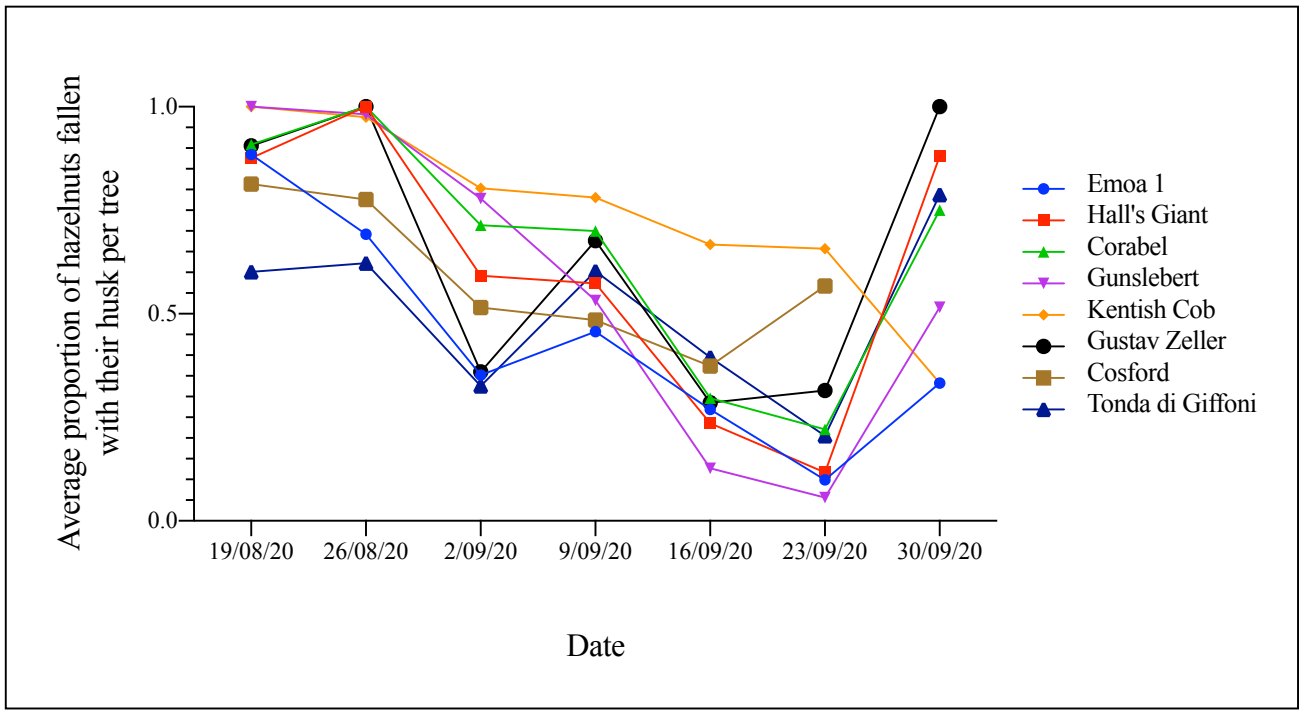


Figure 14 - Proportion of hazelnuts fallen with their husk by variety over time.

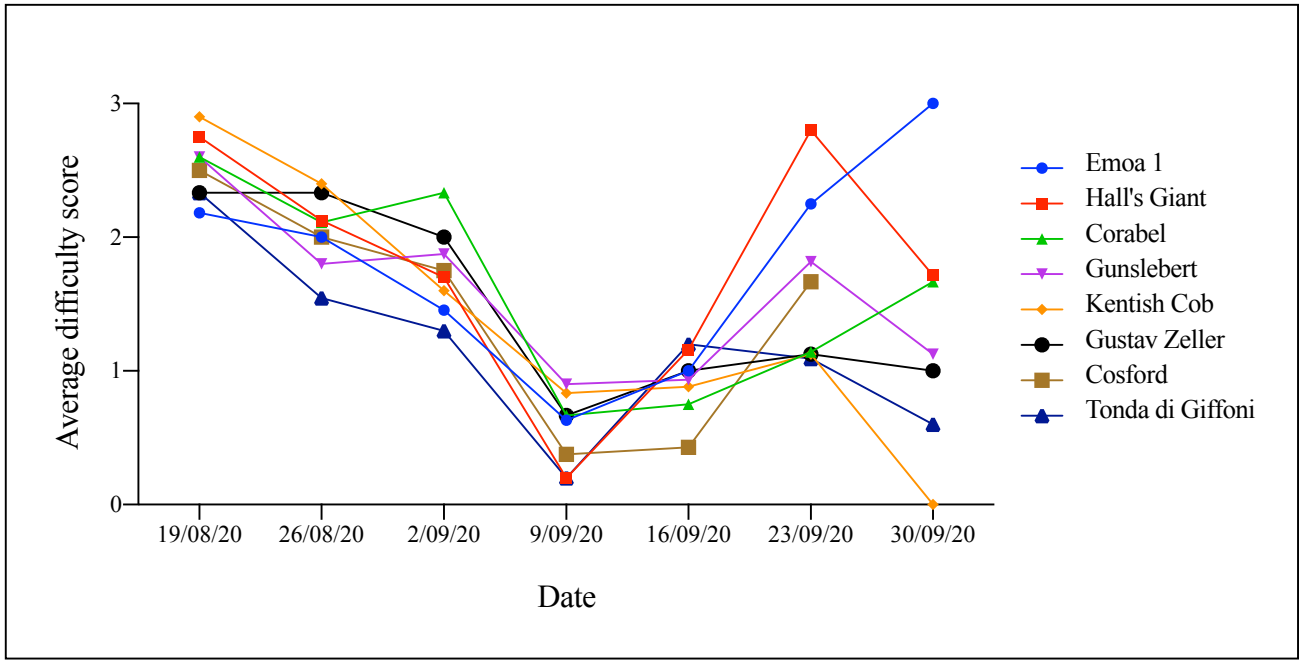


Figure 15 - Average difficulty score to remove the husk by variety over time.

The first figure 14 above shows the proportion of hazelnuts that has fallen with their husk by variety over time. The variety 'Gunslebert' has the smallest proportion, around 15% in total. On the contrary, nearly 70% of the nuts of 'Kentish Cob' fell in their husk. From the 09/09/2020, the hazelnuts where still collected on the ground but after the trees were shaken. It was a compromise made in order to avoid

losses due to animal predation. This can be seen in the figure 15: on the 09/09/2020, there is a revival of the proportion of hazelnuts fallen with their husk while the trend was declining.

The reasoning was also that if the difficulty score was low, it meant that the hazelnuts would have fallen by themselves in the upcoming days anyway, and thus shaking the trees wouldn't distort the time distribution. Figure 15 shows that effectively, the difficulty score from the 09/09/2020 was low, meaning that hazelnut would have fall by themselves in the next few days.

1.5. Kernel yield

Table 8 below shows the mean kernel yield by variety, which is considered as the ratio of the weight of the kernel on the total weight of the hazelnut (kernel + shell). The higher it is, the heavier is the kernel or the lighter is the shell. 'Cosford' presents by far the highest cracking yield, with 59.1% in average. 'Gustav Zeller', 'Emoa 1', 'Hall's Giant' and have low cracking yield, 45.2%, 45.4% and 46.3% respectively.

Table 8 - Mean cracking yield by variety

Variety	Cracking yield	Std. Error
Emoa 1	45.4%	0.71%
Halle's Giant	46.3%	0.88%
Corabel	49.7%	0.98%
Gunslebert	47.8%	0.91%
Kentish Cob	49.4%	0.89%
Gustav Zeller	45.2%	0.95%
Cosford	59.1%	1.16%
Tonda di Giffoni	48.5%	0.87%

2. Tree monitoring

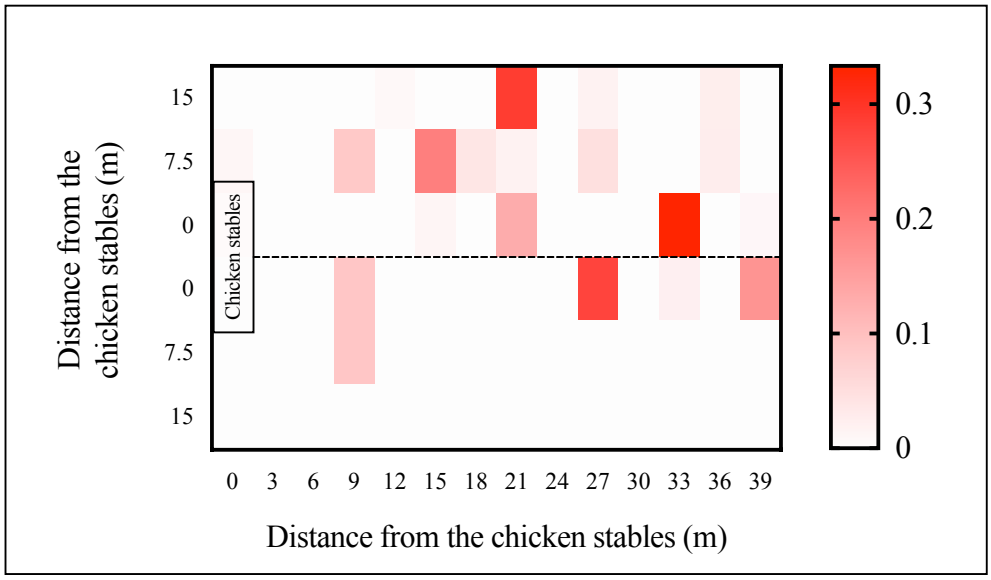
2.1. Health of the tree through Leaf Damage Score

Brown spots on the leaves and on the margins are consequences of sunburn scorches or K deficiency. These damages could impact the productivity of the tree. Integrating this score into the model didn't turn out to be significant (p-value=0.2359). The intensity of chicken pressure on the field, however, influenced this Leaf Damage Score significantly (p-value=0.001). If the intensity was raised by one unit, the score decreased by 0.31. As the percentage of good leaves on a tree was defined by a low Leaf Damage Score, it meant that, if the intensity of chicken pressure raised, the percentage of good leaves diminished. This score was as well influenced by the variety (p-value<0.001). The varieties presenting a better score compared to the variety 'Emoa 1', took as reference by RStudio, are 'Cosford', 'Kentish Cob', 'Tonda di Giffoni' and 'Hall's Giant'. On the other hand, the varieties presenting a lower score are 'Gunslebert', 'Gustav Zeller' and 'Corabel'.

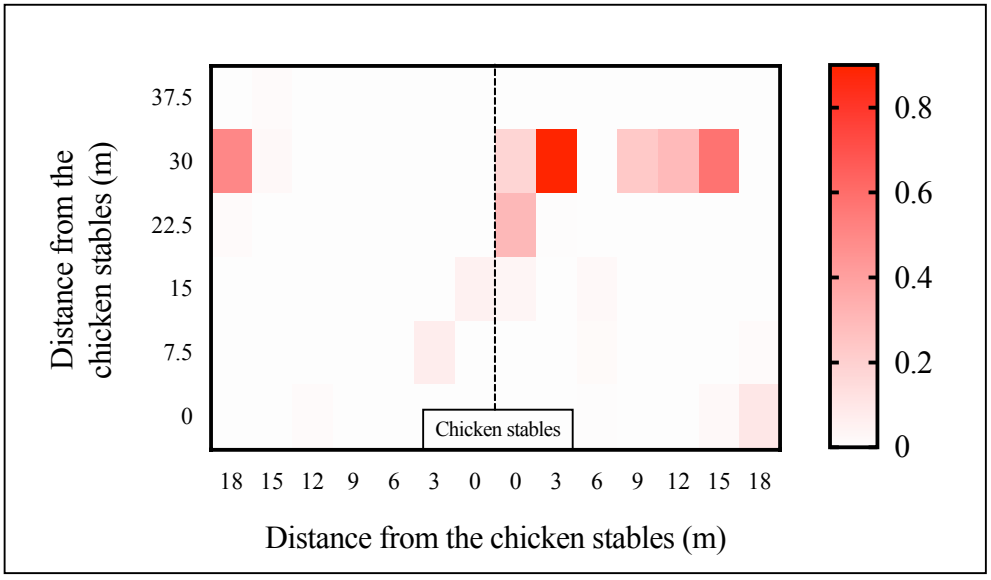
2.2. Impact of insects and other predators

2.2.1. Nut weevil

Hazelnuts presenting a small hole in the shell, caused by the hazelnut weevil larvae, was the damage the most observed. It reached 2.2% of the harvest, and up to 9.67% for the variety 'Cosford'. The variety was a parameter highly significant (p-value<0.001) to explain the percentage of hazelnuts eaten by the hazelnut weevil. The most affected varieties are 'Cosford', 'Corabel' and 'Emoa 1'. The least affected varieties are 'Hall's Giant', 'Gunslebert' and 'Kentish Cob'. The presence of chickens on the field can be a method of fighting this pest. To appreciate this effect, the distance of the trees to the current positions of the chicken stables was used as a variable to explain the percentage of hazelnuts attacked by the nut weevil. The anova test revealed the significance of this variable (p-value=0.02892) and the fixed effects showed that for every meter away from the chicken stable, the average percentage of eaten hazelnuts raised by 0.18%. The figure 16 below helps to visualize the level of predation by the hazelnut weevil on the field. Each rectangle represents a tree and the color associated to it reveals its percentage of hazelnuts attacked. The black dotted line crossing the field is the separation between two chicken groups.



(a)



(b)

Figure 16 - Heat maps of the percentage of nut weevil predation on each tree on (a) plot A and (b) plot D.

2.2.2. Other predators

On all the hazelnuts harvested, only 0.55% were showing damages due to rodents with a peak at 1.31% for the variety 'Gunslebert'. However, these results were not significant (p-value=0.05709). The analysis by camera trap showed rats, crows, hedgehogs and rabbits. Figure 17 shows the different animals captured by these camera traps. The number of days animals were present on the field are shown in table 9. Only one animal at a time was captured on each photo.

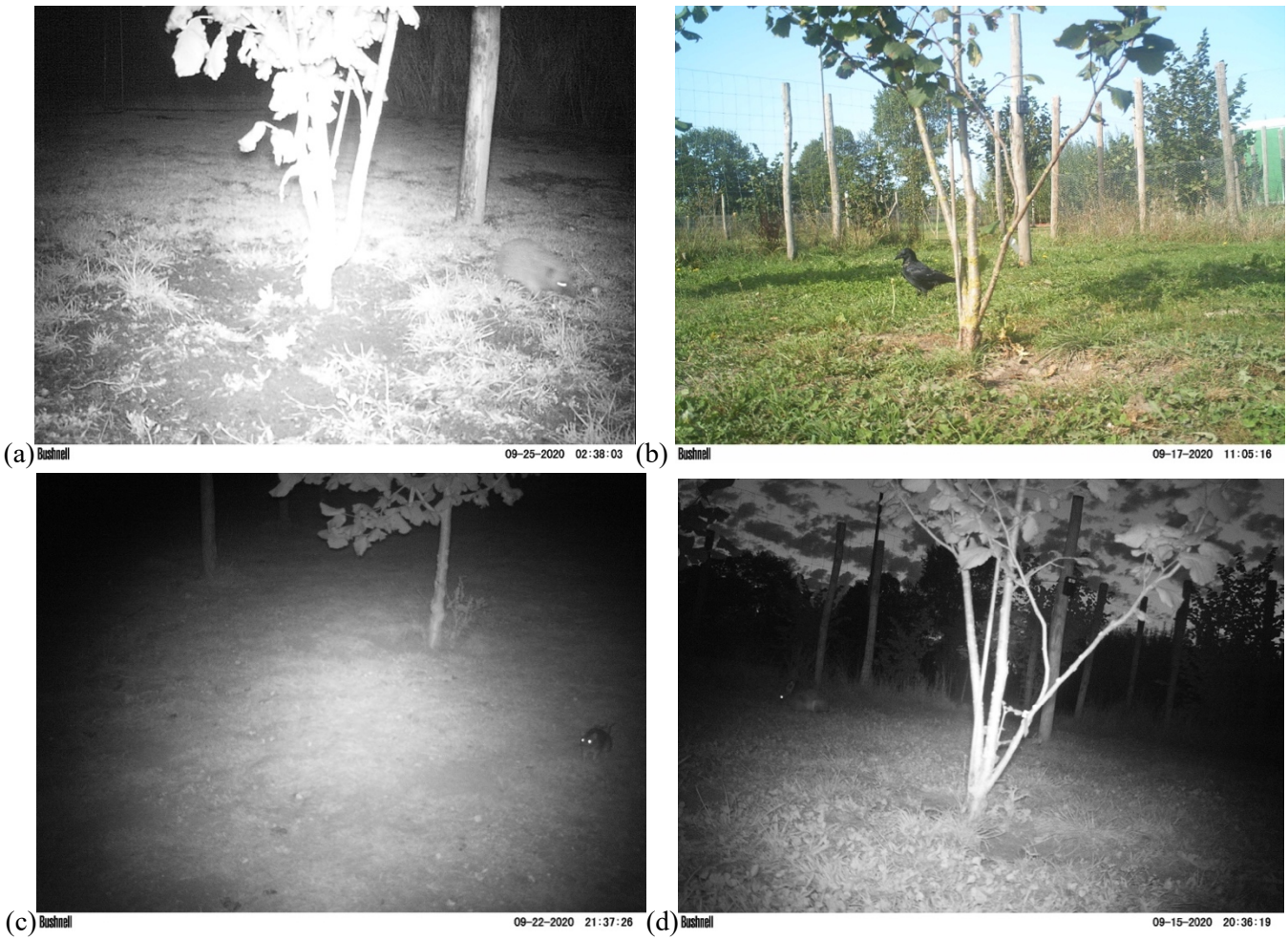


Figure 17 – Camera trap photos showing (a) hedgehog, (b) crow, (c) rat and (d) rabbit.

Table 9 - Number of days a type of animal was captured by camera trapping

	Camera 1	Camera 3	Camera 6	Camera 7
Rabbit	1			
Craw	2		2	
Rat	6	4	5	7
Cat	1			
Hedgehog				2

Table 10 shows that all hazelnuts left on the ground to attract potential eaters were taken away from their initial position and weren't found anywhere close.

Table 10 - Number of hazelnuts left on the ground and the number of hazelnuts taken away

Nr tree	11/09/20	14/09/20		18/09/20
	left on the ground	taken away from previous date	left on the ground	taken away from previous date
48	3	3	3	3
121	7	7	5	5
156	3	3	4	4

The test in which all eight varieties were put at the same place in order to record a preference by animals didn't show any results. The disposal stayed in place for two weeks but no animal visited it. It should be noted that rat poison was placed on the trial few days before the start of the experiment.

3. Yield quality

3.1. Moisture content

Moisture content has a strong impact on the texture of the hazelnut. All varieties have a moisture content between 4.15% and 5.79% as shown in table 11.

Table 11 - Percentage of moisture content by variety.

Variety	%MC
Emoa 1	4.15%
Hall's Giant	5.49%
Corabel	4.44%
Gunslebert	5.09%
Kentish Cob	5.79%
Gustav Zeller	5.25%
Cosford	5.6%
Tonda di Giffoni	4.77%

3.2. Pellicle removal

As shown in table 12 below, the brown pellicle of the varieties ‘Corabel’, ‘Gustav Zeller’ and ‘Tonda di Giffoni’, closely followed by ‘Emoa 1’ and ‘Hall’s Giant’, is removed easily after roasting and rubbing. The ‘Kentish Cob’ kernels remained with most of their pellicle after the same treatment.

Table 12 - Score for the degree of pellicle removal when the kernels have been roasted and rubbed in a towel

Variety	Degree of pellicle removal
Emoa 1	7
Hall's Giant	7
Corabel	8
Gunslebert	6
Kentish Cob	4
Gustav Zeller	8
Cosford	6
Tonda di Giffoni	8

3.3. Microbiological test

The analytical report of the microbiological tests on *E. coli*, yeasts and fungi showed that for all four samples, the values were under a minimum threshold level and were therefore safe for human consumption. Those results are included in Annex 2.

4. Flavor test

4.1. Natural kernels

The comparative taste study results on naturally dried kernels are shown in Table 13. The lowest score is corresponding to the highest preference.

According to this, the ‘Kentish Cob’ variety has a significant higher preference than the ‘Gustav Zeller’ variety (p-value=0.0056). Therefore, ‘Kentish Cob’ is the most preferred among all the others and ‘Gustav Zeller’ the less preferred. All other varieties do not differ significantly.

The comments for varieties ‘Kentish Cob’, ‘Gunslebert’ and ‘Hall’s Giant’ chosen as highest preference pointed out a good hazelnut flavor, slightly sweeter, with no bad after taste and a pleasant texture. For ‘Hall’s Giant’, three panelists referred to a ‘a fatty taste’ or ‘less dry’. One panelist put the ‘Gunslebert’ as less preferred because of ‘less taste’. When the ‘Cosford’ variety was put as first preference, panelists often referred to a ‘juicier’, ‘water feeling’ or ‘not too hard’ kernel. When ‘Gustav Zeller’, ‘Corabel’ and ‘Tonda di Giffoni’ were put as least preferred varieties, the comments revealed that the kernels had no

taste, a bad texture (leave a feeling of dry mouth or stick to the mouth after eating) or were not crispy. Particularly the 'Gustav Zeller' seems to have a bad or too neutral taste, one panelist even pointed out it had a strange chemical taste. The commercial kernels from Turkey were, when they received the least preferred score, frequently referred as bitter and dry. But, when referred as first preference, the particularity 'good taste' was pointed out.

Four comments referred to the external shape of the hazelnuts. The 'natural' and 'nice' shape adjective was used when the 'Hall's Giant' and 'Cosford' varieties were put as most preferred and the 'industrial' adjective to refer to the appearance of 'Emoa 1' when put as least preferred.

Table 13 - Results of the sensory test on naturally dried kernels of hazelnuts

Variety	Ranking
Emoa 1	163^{ab}
Halle's Giant	135^{ab}
Corabel	171^{ab}
Gunslebert	119^{ab}
Kentish Cob	108^{b}
Gustav Zeller	178^{a}
Cosford	145^{ab}
Tonda di Giffoni	169^{ab}
Commercial (Turkey)	162^{ab}

a,b value with a different letter in the same column per test significantly differ ($p<0,05$)

4.2. Roasted kernels

No significant differences in preference were observed between the roasted hazelnuts.

IV. Discussion

The purpose of the present study was to evaluate the potential of hazelnut production in an agroforestry context in Belgium and The Netherlands. Through assessing the growing characteristics of eight different varieties of hazelnut trees, as well as on quality and taste of the kernels. Along with understanding the hazelnut market.

1. Productivity: what to expect

The 2020 harvest revealed differences of production among the eight varieties in place. The most productive variety was 'Kentish Cob' and the least productive 'Cosford'. Unfortunately, the management type couldn't be used to explain differences in productivity within the variety. In this trial, the management type was associated to the variety at plantation, hence, the 'shrub' varieties, namely 'Hall's Giant', 'Kentish Cob' and 'Cosford', don't have trees in 'Gobelet'. Moreover, the few number of trees that went from the 'Gobelet' shape to the 'shrub' shape may not have been sufficent to detect a difference in production. Especially as the trees are still very young, which may mean that the influence of this parameter may not yet be felt on the production. However, this parameter should continue to be researched if trees are being left to grow in the 'shrub' shape.

This trial has only one year of hindsight on production (through 2019 harvest). The comparison to 2019 harvest has shown some great differences in production in between the two years. In this trial, the very young age of the trees plays a role but this trend is also noticeable on global hazelnut production (FAO, 2020). Indeed, hazelnut production is affected by strong inter-annual yield fluctuation (Ascari et al., 2020). This phenomenon, common in other fruit crops, is termed 'biennial bearing' or 'alternate bearing' and consists in a high fruit production (ON-Crop) in one year, inhibiting flowering the following year and therefore inducing a low fruit production (OFF-Crop) (Smith and Samach, 2013; Ascari et al, 2020). The cause of biennial bearing is the competition for nutrients between the growing fruits and those undergoing differentiation (Boulay and Mainié, 1966); late-ripening fruit species are therefore more prone to biennial bearing (Boulay and Mainié, 1966). Management practices can mitigate this phenomenon, such as pruning, flower and fruit thinning (Smith and Samach, 2013) and by regular manuring of orchards (Boulay and Mainié, 1966). Beside this biennial bearing, hazelnut production is also affected by weather conditions. Unfortunately, full data from the weather stations at ILVO is not available and the variations in productivity between 2019 and 2020 cannot be explained through accurate weather conditions, regarding the hazelnuts needs in rainfall, temperature, relative humidity and wind described in point 8 of the State of the Art. Another approach to this discrepancy could be the lack of fertilization and pruning management during the year. Indeed, management and care are very important during the early years of hazel trees (pers. comm. Harm Tuenter). The management is important to let the light come inside the tree for sufficient renewal of annual shoots (Germain and Sarraquigne, 2004). For vigorous varieties such as 'Hall's Giant, 'Corabel' and 'Cosford' (FAO, 2000), the lack of pruning, and therefore the lack of light, could explain the drop in production between 2019 and 2020.

A first important point to look for in the next years, is to link weather conditions throughout the year to phenological stages and final production. Indeed, each variety has optimal ranges but it remains to be determined if the weather conditions in Belgium and The Netherlands allow optimal production of the varieties planted at ILVO.

In this experimental trial, each of the eight varieties is represented equally, 21 trees for each. In a plantation for real commercialization objectives, we distinguish two purposes for choice of varieties: the main varieties that are relevant for the production and the pollinating varieties to pollinate the main varieties. In practice, the pollinating varieties only represent 8 to 12% of the total number of trees (Germain and Sarraquigne, 2004). In practice, the pollinating varieties are 'Cosford' and 'Kentish Cob'; 'Gunslebert', 'Gustav Zeller' and 'Tonda di Giffoni' are used as main varieties and 'Hall's Giant' and 'Corabel' can be both. The choice of the varieties and in which proportions they will be planted is up to the producer. The characteristics of the different varieties have to be known in order to choose the market to focus on. A high productivity is certainly an important point, but other characteristics such as the difficulty to remove the husk, the taste and aspect or the degree of pellicle removal must also be taken into account (pers. comm. Harm Tuenter).

1.1. Difficulty to remove the husk

If the husk doesn't come off the hazelnut easily, it can add extra processing work to remove it. The results of this study showed that during the efficient harvesting period, all the varieties easily removed from their husk (or during mechanical harvesting operations (Germain and Sarraquigne, 2004)) or most of the hazelnuts fell without it, except for the variety 'Kentish Cob' for which a high percentage (70%) of hazelnuts fell with their husk. This can be explained by the morphology of its husk, which is longer than the nut with the ends folding over the nut (Figure 18), preventing the nut to fall.

Figure 18 – Husk of 'Kentish Cob' tightening the nut.

1.2. Taste, aspect, moisture content and total oil

Unfortunately, the aspect hasn't been a parameter analyzed during the taste trial but could be subject of further investigation. Indeed, markets pay more attention to appearance than taste (pers. comm. Ton

Baltissen) and it is to note that four comments of the taste trial referred to the shape of the kernel without being asked to, proving that this parameter has importance.

Regarding the taste results, preferences are highly variable and only two significant results could be drawn. The difficulty of the test must be stressed. Indeed, nine varieties to try at once is difficult, and only one kernel by variety was available for each panelist. If the hazelnut industry requires further study on the subject, it is recommended to only taste maximum five nuts at a time. Then, the most preferred hazelnut of this first panel should be integrated into the next panel (four other varieties to taste) in order to link the successive panels together. Also, more than one kernel should be available for each panelist as kernels may have turned bad and thus, don't reflect the real taste.

A high moisture content is linked to a better texture of the kernels. Indeed, when panelists referred to 'pleasant texture', 'juicier', 'water feeling' and 'not too hard' (adjectives used to describe highest preference), it corresponds to the highest moisture content. Similarly, the 'dry' and 'not crispy' textures (adjectives used to describe lowest preference) corresponds to low moisture content. However, those relations remain to be statistically confirmed. In addition, oil content measurements could be performed to link this factor to the taste/texture and moisture content. Indeed, oil content and quality of different hazelnut varieties is not yet well-known (pers. comm. Harm Tuenter). Moreover, the oil industry could be interested in those results as a liter of oil can reach 40€ a liter.

1.3. Degree of pellicle removal

Varieties having good blanching characteristics are wanted for specific types of manufactories. Knowing which varieties release easily from their brown pellicle is therefore important in order to sell them separately from the rest of the production. This extra work of selection justifies a higher price charged by the producer (+2€/kg) (pers. comm. Harm Tuenter). The variety 'Gustav Zeller' is planted as main variety because it gives with kernels (pers. comm. Harm Tuenter) but the results showed that 'Corabel' and 'Tonda di Giffoni' had the same degree of pellicle removal. 'Emoa 1' and 'Hall's Giant' were just a level below. On the other hand, 'Kentish Cob' showed the worst result, with most of the kernels remaining with the brown pellicle after roasting and rubbing.

In practice, most growers don't know yet which market they want to focus on when starting a hazelnut plantation, and to keep all possibilities accessible, they plant different varieties. This study has shown that varieties considered as pollinating varieties showed great results, namely 'Kentish Cob' in 2020 and 'Hall's Giant' in 2019. They could therefore become a main variety and be planted in higher proportions, while keeping its role of pollinator. It is to be explored if the trend keeps going in the following years. Especially as 'Kentish Cob' showed the higher preference in taste as well. But a way to remove its husks easily remains to be found.

2. Agroforestry context

The hazelnut variety trial is part of a silvopastoralism experimental field with free-range chickens. The benefit of such an association is already visible at this end of this assessment. Indeed, it has been shown that the more a tree is in contact with chickens (short distance to the shelter and higher number of

chickens), the more it produces. Although our assessment was only a preliminary screening on how chicken manure influences tree productivity, it is clear that this is a topic that needs further investigation through soil sampling and analysis.

The presence of chicken on the field had had a secondary impact: the trees close to the chicken stables presented less nut weevil damages. According to Crawford (2015), chickens eat overwintering pupae. To spread this trend to entire field, chickens should better use their free-range. Indeed, Bracke et al. report (2020) pointed out that chickens don't use the field in its entirety and were staying close to the chicken stables. A solution that is currently experimented during the round 3 of chicken trial, is the positioning of mangers in different places of the field, to encourage chicken to use all the space at their disposal (pers. comm. Michael Plante Ajah). Another benefit derives from this association: better health and animal welfare (Anil et al., 2018; Rocchi et al., 2019; Bracke et al., 2020) and meat and eggs of higher quality (Castellini et al., 2006; Bracke et al., 2020).

Furthermore, the microbiological tests realised on hazelnuts that have been washed at 70°C for one minute have shown no microbiological risks. Therefore, growers who want to associated chickens and hazelnut production are not facing major health risks if this minimum washing is realised. However, porosity characterization of the shell should be furthered explored. Indeed, if the water pierces the shell, the kernel quality may be affected.

The arrangement of the willow plots (B and C) didn't influence either of the two hazelnut plots (A and D) in terms of production. However, different agroforestry configurations and associations could impact significantly a hazelnut orchard by creating a favorable microclimate. As seen in point 8. of State of the Art, hazel trees are sensitive to various climatic conditions, such as rainfall (but can be controlled with irrigation), temperature, relative humidity and wind. Cultivating them in an agroforestry context can help mitigate critical values of these parameters, in addition to the benefits mentioned above. Improvement of the microclimate thanks to wind screens (made of *Sambucus nigra* L. for instance (pers. comm. Harm Tuenter)) on all sides of the plantation are recommended (Wertheim and Goedegebure, 1988). In agroforestry systems, plantations densities are lower than in conventional systems. In this trial, the trees are planted 7.5 x 3 m (444 trees/h) compared to 555 trees/ha (6 x 3 m) to 800 trees/ha (5 x 2.5 m) (Germain and Sarraquigne, 2004). This low density allows a low competition for light (Germain and Sarraquigne, 2004) which is more suitable for highly vigorous varieties. Moreover, trees evaporate more in semi-open spaces due to a better water absorption made by a more developed root system (Dupraz and Liagre, 2011). Therefore, relative humidity rises, protecting the herbaceous layer from desiccation (Dupraz and Liagre, 2011).

3. Harvesting period

In Turkey, hazelnuts are hand-picked from the trees. In European countries and in the USA, hazelnuts are collected from the ground with machinery (Hüseyin et al., 2019). Several factors are taken into account to determine the number of times the machines pass in one season: the weather conditions, the time of maturity of each variety, the stabilization capacity (sorting, washing drying), the animal predation, human resources and available machinery (Germain and Sarraquigne, 2004). In France, harvest happens twice during the season, or even three times depending on the resources available and the weather conditions (Germain and Sarraquigne, 2004).

Regarding the results about time distribution (Figure 12 & 13), the best time to make a first harvest would be during the fourth/fifth week and a second harvest at the end of the sixth week, just before empty hazelnuts start falling again. These harvesting periods also correspond to the time when hazelnuts don't fall with their husk, or if they do, the husk is removed easily, making further processing steps easier.

However, general maturity of the orchard can be delayed or early (up to 10 or 12 days (Germain and Sarraquigne, 2004)) from one year to another depending on the weather conditions during the year. But even in this case, early varieties will always fall before the late varieties (pers. comm. Ton Baltissen).

In addition, the soil needs to be prepared before harvest to facilitate machinery work. Another pre-harvest operation can also be made: a first collect of bad hazelnuts because for most varieties, empty hazelnuts fall in advance. As efficient harvesting only starts after three or four weeks after the first hazelnuts have fallen, this pre-harvest operation allows to remove nuts from the ground so that no predators are attracted. This operation, based on our results, would be relevant to happen by the third week. Indeed, by that time, the varieties 'Kentish Cob' and 'Tonda di Giffoni', even if they have already a low proportion of empty nuts, have only lost a small proportion of their total nuts (less than 5% for 'Kentish Cob' and around 13% for Tonda di Giffoni'). For the other varieties, they still show a high percentage of empty hazelnuts (>50%). For a grower that decides to plant a mix of all these varieties, remove the hazelnuts by the third week, all varieties combined, wouldn't be therefore an important loss of good hazelnuts, based on the results of this trial. In the case growers decide to collect the good hazelnuts among those pre-harvested hazelnuts, the simple action of immersing the hazelnuts in a basin of water makes it possible to collect them because the good hazelnuts sink.

4. Animal monitoring

Damage caused by the hazelnut weevil on average affects 5-10% of the nuts but these damages can reach up to 80% (Solar and Stampar, 2011). This year, in our trial, the hazelnuts of the 'Cosford' variety were most affected (9.67%), which might be due to their thin shell (Germain and Sarraquigne, 2004). This variety doesn't show a potential for production but its presence on the field can have a double purpose: first it is used as a pollinating variety and second, it could serve as hazelnut weevil traps, protecting the other varieties.

Regarding other predators, the data was not sufficient enough to make strong conclusions. An unknown proportion of hazelnuts might have been taken away in nests. The idea of installing the camera traps on the field was to observe what predators were eating the hazelnuts, to what extent and whether they eat directly on the field or move them. It turned out that nearly all the hazelnuts disappeared. Since hazelnuts of each tree weren't harvested every day, an unknown proportion of nuts have certainly been lost in between. An interesting path to further explore would be to count all the nuts of one tree before they start falling and to compare that number to the final number harvested. In this way, a real appreciation of the importance of this parameter could be achieved as well as a precise quantification of the loss at the trial scale.

The additional test in which hazelnuts of all eight varieties were put at the same place in order to assess a potential preference by animals, gave no results. The rodents have certainly been killed previously by the

poison. What is disconcerting is that no birds came, whereas the nuts where clearly visible. Anyway, the data collected this year were clearly not sufficient, hence this issue deserves a more in-depth monitoring in the subsequent years.

V. Personal contribution of the student

As hazelnut production in Belgium and The Netherlands is nearly insignificant, very few researches on this topic are being conducted. This hazelnut trial at ILVO allows to better understand growth and productivity of different varieties of hazelnut in the Belgian and Dutch climate. This study is part of a long-term research and was only the second assessment of the trial. However, it allowed to improve the 2019 harvesting protocol, which was less elaborated, to apply it to the following years. It also highlighted potential interactions due to mixed cropping systems and proved that they deserved further investigation.

In parallel, this study tried to gather information about economic and marketing opportunities and difficulties of hazelnut production in these countries. It is hoped that it will enlighten, reassure and inspire future hazelnut growers to embark into this journey, and preferably in a sustainable way like agroforestry.

VI. Conclusion

A future hazelnut production in Belgium and The Netherlands at greater scales shows a real potential in producing a high-quality product to create a parallel market to the Turkish supply. Current Belgian and Dutch producers already find a wide range of buyers and the demand is always higher than supply. Big companies are even starting to prospect for new production areas in these regions as they show high yields. The 'Kentish Cob' and 'Hall's Giant' varieties have already shown the highest yields in 2019 and 2020, even if this trend remains to be confirmed in the long term. Various marketable side products also increase the value of a simple hazelnut orchard. The main issues preventing hazelnut production to take off are the high starting costs and the lack of a central structure. In any cases, future growers have to be well informed about what hazelnut production takes before starting in order to avoid failure due to low aftercare and knowledge. Research and experimentation in these regions must continue in order to provide the best varieties for large scale production and adaptation to climate change. Integrating hazelnut trees in an agroforestry context offers various advantages to mitigate undesirable climatic conditions that can affect strongly the hazelnut production. Moreover, there is strong need at the global scale to promote a sustainable agriculture to help mitigate and adapt to climate changes as well to get to a more plant-based diet, and nuts can offer a substitute to animal proteins.

References

Agence fédérale pour la Sécurité de la Chaîne alimentaire, 2017. Transformation et vente à la ferme. Version 4

Agroforestry in Vlaanderen, 2017. Hazelnoot (*Corylus avellana*). Available at: https://www.agroforestryvlaanderen.be/NL/Kennisloket/Praktischeaanpak/Boomspecifiekeinfo/Hazelnoot/tabid/9782/language/nl-BE/Default.aspx

Anil J.B. et al., 2018. How is agroforestry perceived in Europe? An assessment of positive and negative aspects by stakeholders. 829–848, DOI:10.1007/s10457-017-0116-3.

Ascari L. et al., 2020. Relationships between yield and pollen concentrations in Chilean hazelnut orchards. *Eur. J. Agron.* **115**(February), 126036, DOI:10.1016/j.eja.2020.126036.

Atici C., 2013. Food Safety Regulations and Export Responses of Developing Countries: The Case of Turkey's Fig and Hazelnut Exports, 18.

Augère-Granier, M.L., 2020. Agroforestry in the European Union. Available at: https://www.europarl.europa.eu/RegData/etudes/BRIE/2020/651982/EPRS_BRI(2020)651982_EN.pdf

Baldwin B., 2015. The rowth and productivity of hazelnut cultivars (*Corylus avellana* L.) in Australia. PhD thesis. University of Sydney.

Bergoughoux F., Germain E. & Sarraquigne J-P. 1978. *Le Noisetier, production et culture*. Institut national de vulgarisation pour les fruits, légumes et champignons (INVUFLEC).

Boulay H. & Mainié P., 1966. *Arboriculture et production fruitière*. France: Presses Universitaires de France.

Bracke et al., 2020. Meerwaarde creëren in de biologische landbouw door durrzame combinaties van plantaardige teelten met uitloop voor pluimvee: Eindrapport project LEGCOMBIO (2017-2020). ILVO Mededeling 266. ISSN 1784-3197

Castellini C. et al., 2006. Comparison of two chicken genotypes organically reared: oxidative stability and other qualitative traits of the meat. Italian Journal of Animal Science, 5: 1, 29-42, DOI:10.4081/ijas.2006.29.

Crawford M., 2016. *How to grow your own nuts*, Cambridge: Green Books, 320.

Cristofori V., Ferramondo S., Bertazza G. & Bignami C., 2008. Nut and kernel traits and chemical composition of hazelnut (*Corylus avellana* L.) cultivars. **1098** (March), 1091–1098, DOI:10.1002/jsfa.

de Wit L., 2014 *The influence of absenteeism on the Turkish hazelnut sector: A study about the influence on agricultural policies, productivity of agricultural land, and output of the hazelnut sector in Turkey.* MSc thesis. Wageningen University.

Doucet J-L., 2019. *Agroforesterie tropicale* [Diapositives].

Dupraz C. & Liagre F., 2011. *Agroforesterie, des arbres et des cultures*. Paris: GFA.

Fizz by Biosystems, n.d. Analyze your collected data. Available at: https://www.biosystemes.com/en/fizz-software,analyse-your-collected-data.php

Germain E. & Sarraquigne J.-P., 2004. *Le noisetier*. Paris: Centre technique interprofessionnel des fruits et légumes.

Gönenç S., Tanrıvermis H. & Bülbül M., 2006. Economic Assessment of Hazelnut Production and the Importance of Supply Management Approaches in Turkey **107**(1), 19–32.

Gretry M., 2019. C'est une année à noisettes, à la ferme Goffin, à Rosoux. Available at: https://www.rtbf.be/info/regions/liege/detail_c-est-une-annee-a-noisettes-a-la-ferme-goffin-a-rosoux?id=10301266

Hamon X., Dupraz C. & Liagre F., 2009. L'agroforesterie : Outil de Séquestration du Carbone en Agriculture. Available at: https://www.agroforesterie.fr/documents/Agroforesterie-Outil-de-Sequestration-du-Carbone-en-Agriculture.pdf

Hebda T., Brzychczyk B., Francik S. & Pedryc N., 2018. Evaluation of suitability of hazelnut shell energy 1860–1865, DOI:10.22616/ERDev2018.17.N437.

Huhtinen M., 2006. Wood biomass as a fuel. 1–8.

Hüseyin S., Kemal Çağatay S. & Kabaş Ö., 2019. An overview of hazelnut harvesting machines with different designs. Acta Technica Corviniensis. Tome XII [2019]. Fascicule 2 [April - June].

Import Promotion Desk (IPD), 2014. Hazelnuts in Germany 1–15. Available at: https://www.importpromotiondesk.de/fileadmin/user_upload/Publikationen/factsheet/zutaten/Hazelnuts_160225_eng.pdf

IPCC, 2019. Climate change and land. https://www.cncd.be/rapport-giec-climat-terres

İslam A., 2019. Hazelnut culture in Turkey (October 2018), Akademik Ziraat Dergisi. DOI:10.29278/azd.476665.

Lundell M., 2004. *A review of the impact of the reform of agricultural sector subsidization (English)*. Washington D.C.: World Bank Group. https://documents.worldbank.org/en/publication/documents-reports/documentdetail/484361468121476788/turkey-a-review-of-the-impact-of-the-reform-of-agricultural-sector-subsidization

Mehlenbacher S.A., 1991. Hazelnuts (*Corylus*). Leuven: ActaHortic., 290,791-838.

Mélon M., 2016. Hannêche: les noisettes fraîches font recette à Paris et chez nous. Available at: https://www.rtbf.be/info/regions/detail_hanneche-les-noisettes-fraiches-font-recette-a-paris-et-chez-nous?id=9385709

Ministry of Agriculture Nature and Food Quality of The Netherlands, n.d. Combinatieteelt met notenbomen. Available at: https://www.platformkringlooplandbouw.nl/initiatieven-en-inspiratie/notenvereniging

Morcillo M., Sánchez M., Mateu J., Gracia E. & Vidal C., 2007. Inoculation of hazelnut groves with *Tuber brumale* & *Tuber melanosporum* Vitt. In: Proceedings of the 1st world conference on the conservation and sustainable use of wild fungi, Cordoba, 10–16 Dec 2007, Junta de Andalucia, Consejera de Medio Ambiente, p 322

Nair P.K.R., Gholz H.L. & Duryea M.L., 1988. *Agroforestry Education and Training: Present and Future*. Nair, P.K.R., Gholz, H.L., Duryea, M.L. eds., Kluwer Academic, 148.

Nazan A., Turp M.T. & Türke M., 2020. Mid-Term Impact of Climate Change on Hazelnut Yield. Agriculture 10 (5), 159.

Peks A., 2007. Hazelnut husk as a substrate for the cultivation of shiitake mushroom (*Lentinula edodes*). **98**, 2652–2658, DOI:10.1016/j.biortech.2006.09.020.

Perren R. & Escher F. E., 2013. Impact of roasting on nut quality. *Improving the safety of nuts*. Woodhead Publishing Limited. DOI:10.15339780857097484.2.173.

Piskornik Z. et al., 1989. The resistance of hazel (*Corylus avellana*) to hazelnut weevil (*Curculio nucum* L.- *Coleoptera, Curculionidae*). Part II. The physicochemical characteristics of the pericarp and dynamics of nut development and cultivar resistance to the pest. *Acta Agrobot.* **42**, 153–164, DOI:10.5586/aa.1989.012.

Poux X. & Aubert P.-M., 2018. Une Europe agroécologique en 2050 : une agriculture multifonctionnelle pour une alimentation saine. Enseignements d'une modélisation du système alimentaire européen. *Study* **09/18**, 78.

Rainforest Alliance, 2019. UTZ Hazelnut program: Program overview.

Rocchi L. et al., 2019. Assessing the sustainability of different poultry production systems: A multicriteria approach. *J. Clean. Prod.* **211**, 103–114, DOI:10.1016/j.jclepro.2018.11.013.

Shahidi F. & John J. A., 2013. Oxidative rancidity in nuts. *Improving the safety of nuts*. Woodhead Publishing Limited. DOI:10.1533/9780857097484.2.198.

Smith H.M. & Samach A., 2013. Plant Science Constraints to obtaining consistent annual yields in perennial tree crops. I: Heavy fruit load dominates over vegetative growth. *Plant Sci.* **207**, 158–167, DOI:10.1016/j.plantsci.2013.02.014.

Solar A. & Stampar F., 2011. Characterisation of selected hazelnut cultivars: phenology, growing and yielding capacity, market quality and nutraceutical, DOI:10.1002/jsfa.4300.

Uyan M., Alptekin F.M., Cebi D. & Celiktas M.S., 2020. Bioconversion of hazelnut shell using near critical water pretreatment for second generation biofuel production. *Fuel* **273** (March), 117641, DOI:10.1016/j.fuel.2020.117641.

Van Noordwijk M, Coe R, Sinclair FL. 2019. Agroforestry paradigms. In: van Noordwijk M, ed. Sustainable development through trees on farms: agroforestry in its fifth decade. Bogor, Indonesia: World Agroforestry (ICRAF) Southeast Asia Regional Program. pp 1−14.

Wells M. L., 2013. Agricultural practices to reduce microbial contamination of nuts. *Improving the safety of nuts*. Woodhead Publishing Limited. DOI:10.1533/9780857097484.1.3.

Wertheim S.J. & Goedegebure J., 1988. De teelt van hazelnoten. Publikatie / Consulentschap in Algemene Dienst voor de Fruitteelt in de Volle Grond en Proefstation voor de Fruitteelt : nr. 6

Websites sources consulted

Food and Agriculture Organization of the United Nations http://www.fao.org/faostat/en/#data/QC, (consulted on 15/12/2020)

Institut Royal de Météorologie de Belgique
https://www.meteo.be/fr/climat/bilans-climatologiques/2020/decembre

StatBel
https://statbel.fgov.be/nl/themas/landbouw-visserij/land-en-tuinbouwbedrijven#figures, (consulted on 21/11/2020)

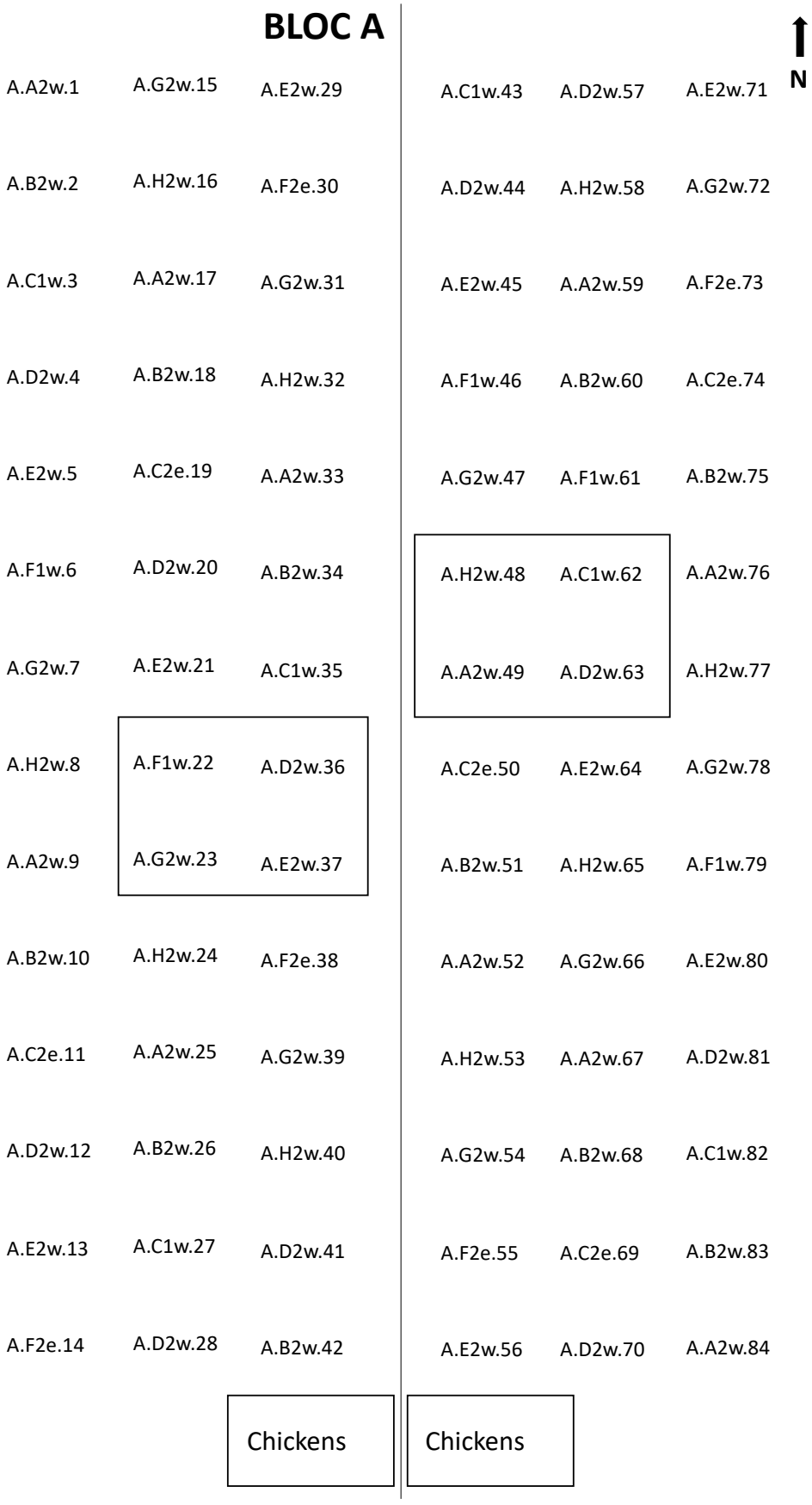
Wikipedia

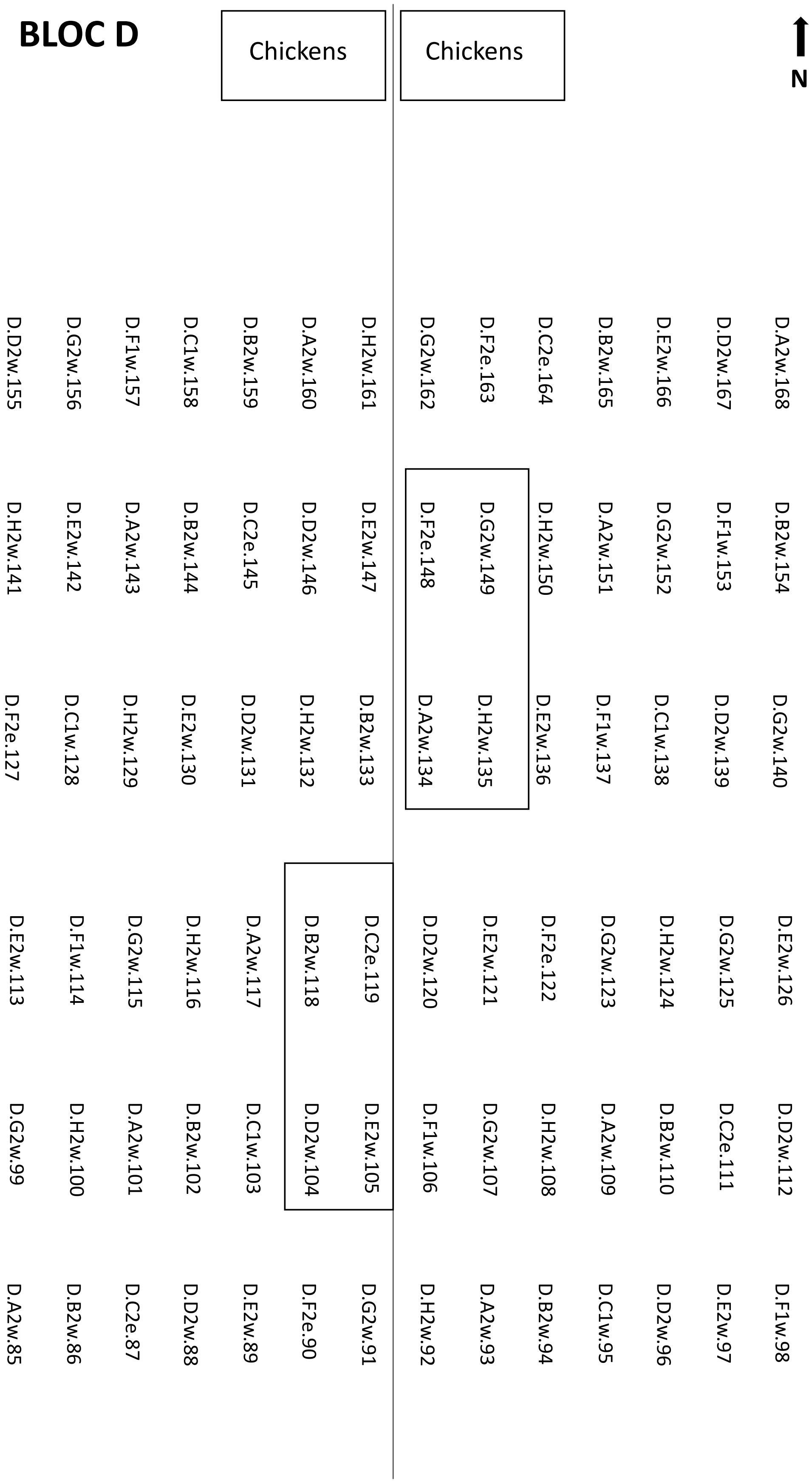
- "Grafting", 2020, (consulted on 23/12/2020)
- "*Curculio nucum*", 2020, (consulted on 23/12/2020)

World Health Organization
https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight, (consulted on 05/08/2020).

Appendices

Appendix 1: Arrangement of the trial

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D.A2w.151
D.H2w.150
D.G2w.149
D.F2e.148
D.E2w.147
D.D2w.146
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D.H2w.141
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D.C1w.138
D.F1w.137
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D.C1w.128
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D.B2w.110
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Appendix 2: Results of the microbiological tests

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04/11/2020

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Geachte,

Hierbij heb ik de eer U het beproevingsverslag te laten geworden van de bepaling(en) uitgevoerd op het/de hieronder vermelde monster(s).

Monstertype	:	vast levensmiddel
Monsteridentificatie klant	:	noten (Sofie Jeanmart) nr B
Identificatie labo T&V	:	2020/010983
Datum & tijdstip ontvangst	:	23/10/2020 om 11u30
Verzegeling	:	niet verzegeld
Toestand monster	:	goede staat

Analyse	Analysemethode		Datum analyse	Resultaat
Telling van *Escherichia coli* bij 44°C	Rapid'E.coli 2 - AFNOR BRD-07/01-07/93		26/10/2020	< 10,0 kve/g
Telling van gisten bij 25°C	ISO 7954 (1987)		26/10/2020	$9{,}1.10^{0}$ kve/g (geschat aantal)
Telling van schimmels bij 25°C	ISO 7954 (1987)		26/10/2020	< 10,0 kve/g

Monstertype	:	vast levensmiddel
Monsteridentificatie klant	:	noten (Sofie Jeanmart) nr D
Identificatie labo T&V	:	2020/010984
Datum & tijdstip ontvangst	:	23/10/2020 om 11u30
Verzegeling	:	niet verzegeld
Toestand monster	:	goede staat

Analyse	Analysemethode		Datum analyse	Resultaat
Telling van *Escherichia coli* bij 44°C	Rapid'E.coli 2 - AFNOR BRD-07/01-07/93		26/10/2020	< 10,0 kve/g
Telling van gisten bij 25°C	ISO 7954 (1987)		26/10/2020	< 10,0 kve/g
Telling van schimmels bij 25°C	ISO 7954 (1987)		26/10/2020	< 10,0 kve/g

Monstertype	:	vast levensmiddel
Monsteridentificatie klant	:	noten (Sofie Jeanmart) nr E
Identificatie labo T&V	:	2020/010985
Datum & tijdstip ontvangst	:	23/10/2020 om 11u30
Verzegeling	:	niet verzegeld
Toestand monster	:	goede staat

Analyse	Analysemethode		Datum analyse	Resultaat
Telling van *Escherichia coli* bij 44°C	Rapid'E.coli 2 - AFNOR BRD-07/01-07/93		26/10/2020	< 10,0 kve/g
Telling van gisten bij 25°C	ISO 7954 (1987)		26/10/2020	$1,5.10^2$ kve/g
Telling van schimmels bij 25°C	ISO 7954 (1987)		26/10/2020	$1,7.10^2$ kve/g

Monstertype	:	vast levensmiddel
Monsteridentificatie klant	:	noten (Sofie Jeanmart) nr H
Identificatie labo T&V	:	2020/010986
Datum & tijdstip ontvangst	:	23/10/2020 om 11u30
Verzegeling	:	niet verzegeld
Toestand monster	:	goede staat

Analyse	Analysemethode		Datum analyse	Resultaat
Telling van *Escherichia coli* bij 44°C	Rapid'E.coli 2 - AFNOR BRD-07/01-07/93		26/10/2020	< 10,0 kve/g
Telling van gisten bij 25°C	ISO 7954 (1987)		26/10/2020	< 10,0 kve/g
Telling van schimmels bij 25°C	ISO 7954 (1987)		26/10/2020	$3,6.10^1$ kve/g (geschat aantal)

Opmerkingen:

/

Laboratoriumverantwoordelijke(n): Dr. ir. K. De Reu

Paraaf:

De eindverantwoordelijke

Dr. L. Herman, Afdelingshoofd