

Article

Is Hazelnut Farming Sustainable? An Analysis in the Specialized Production Area of Viterbo

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Abstract: Specialized agricultural systems may have a strong environmental impact, thus affecting the sustainability of production. The aim of this study is to evaluate the overall environmental impact of the hazelnut production, focusing on the main Italian production area, which is located in the province of Viterbo (central Italy). The theoretical approach adopted in this study refers to the paradigm of ecological economics, recalling the concept of strong sustainability through the conservation of natural capital and its non-replacement with economic capital. This environmental sustainability of farming systems is assessed through the ecological balance (EB) tool by comparing the availability and use of natural capital in each farm scenario. This allows to understand the extent of the load generated on the environment by the different farm's typologies, as well as the impact on the entire territory where hazelnut cultivation is predominant. For the assessment, local typical farm scenarios are assessed through a Delphi consultation of a panel of experts, thus characterizing the cultivation techniques most frequently adopted in the area. Three typologies of representative farms emerge, which mainly differ for cultivation method and dimension. Cultivation methods associated with the larger farms (both conventional and organic) generate a positive contribution to EB, whereas small farms (conventional) have a negative EB due to the high utilization of inputs. However, the positive balance of the large farms compensates for the negative balance of the small ones. This determines a total positive environmental balance of the specialized production area of Viterbo, equal to 9412 gha. This means that hazelnut farming at a territorial level is sustainable thanks to specific farm managements, which can be promoted by policy-makers.

Keywords: *Corylus avellana*; sustainability; ecological footprint; ecological balance; Delphi method



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1. Introduction

Recently, the production of hazelnuts has attracted attention due to the growing demand of the product from confectionery companies and, at the same time, to the increase in the economic performance of hazelnut farming systems. As a result, there has been an intensification of the world surface area of hazelnut trees, from 607,427 hectares in 2010 to more than one million hectares in 2019 [1–3].

Such an increase has raised the attention over the risk of monoculture in some production areas. The scientific literature generally uses the concept of monoculture to emphasize agricultural areas where there is a strong specialization of crops. Two different explanations of the term can be given. The first interpretation reflects the viewpoint of the farm, which recognizes monoculture as the cultivation of the same plant species, repeated on the same field for several years in a row; the second one is in a territorial perspective, which links

the concept of monoculture to the predominant subsistence of a crop in a territorial area covering a considerable number of hectares. The latter corresponds to a high level of specialization for a specific crop in an agricultural region.

In the regions with a high level of agricultural specialization, it is particularly important to assess and monitor the environmental impact of the cultivated crops to determine if the specialization leads to a sustainable or unsustainable farming system. Indeed, sustainability issues are becoming increasingly important, considering the current environmental challenges related to climate change, pollution, and the scarcity of natural resources.

Over the centuries, the world's economies have witnessed the technological and productive strengthening that has led to improvements in agricultural activities, but which, at the same time, has given rise to serious environmental issues that mankind has faced and will continue to face for the coming decades [4,5].

Agriculture and food systems, in addition to being particularly sensitive to atmospheric changes and soil deterioration, have a high environmental impact on biodiversity, on GHG emissions, and on pollution related to the use of fertilizers and other agricultural raw materials [6–8]. The path to achieve sustainable agricultural production systems is still very long [9]; for this to happen, it is necessary, on the environmental side, to deal with the sudden climate changes and the problems related to the pollution of production processes.

Recently, the need to maintain and improve the sustainability of production processes has pushed the research to find methods to measure and monitor the level of the environmental sustainability of systems [10]. Different methods of environmental assessment in agriculture have been proposed, developed, and implemented [11]; these include the Life Cycle Assessment (LCA) and the Ecological Footprint.

LCA is widely used as an assessment tool. It performs an analytical environmental assessment for individual products, allowing the calculation of their environmental impact as the sum of the impacts of the different phases that have generated it [12]. However, given the subjectivity that characterizes the choice of the boundaries of analysis and their level of detail, it leads to results that are difficult to compare. This means that products made with similar processes in different companies can be characterized by significantly different environmental performances [13,14]. Another critical aspect of this methodology, when applied to agricultural processes, is that it does not consider the role of biological systems that contribute directly or indirectly to environmental sustainability [15].

Another approach that considers the ecological functions of agriculture and that leads to the definition of a synthetic index able to quantify them is the Ecological Footprint (EF). Introduced by Rees in 1992 [16] and developed by Rees and Wackernagel in 1994 [17], the Ecological Footprint allows the comparison between the demand for natural capital by the economic activity/production process under study, expressed by the Ecological Footprint Indicator (EF) and the supply of natural capital measured by the BioCapacity (BC).

The EF measures the consumption of natural resources by a given human activity within a well-defined territory and is expressed in global hectares (gha); BioCapacity (BC), also expressed in global hectares (gha), measures how much bioproductive area is available in the same analysis territory. The comparison between these two values, defined as Ecological Balance ($EB = BC - EF$), expresses the balance between the availability and use of natural capital, highlighting a situation of surplus/environmental deficit which corresponds to a “quantified” condition of sustainability or unsustainability.

This methodology is particularly suitable for the assessment of the strong sustainability condition, intended for the preservation of natural capital, human activities, and agricultural production [18–22], which is the approach adopted in this study. Therefore, we use the ecological footprint approach both for the evaluation of the environmental sustainability of the hazelnut production on a farm scale and for the assessment at regional level, which are the main objectives of this research.

At the international level, Turkey is the main producer of hazelnuts, with a global production exceeding 70%, whereas Italy is the second-world producer, both in terms of production volumes and cultivated area [1,2,23,24]. Highly specialized areas of hazelnut

production in Italy are located in Piedmont, Lazio, Campania, and Sicily, which have favorable environmental and socio-economic conditions [1,25]. The province of Viterbo ranks first in the production of hazelnuts, representing an average of 30% of national production [2]. The cultivar used in this area is registered as a Protected Designation of Origin (PDO) with the name “Tonda Gentile Romana”. The production process takes place on-site, except for the final processing of the product, which is carried out at confectionery companies located in other Italian regions [1].

Moving from this framework, this study aims to evaluate the environmental impact of a specialized agricultural system, such as the hazelnut production area within the province of Viterbo. This paper describes the objectives, methodologies, and results emerging from the assessment of the environmental sustainability of hazelnut production, performed both on a farm scale and at a territorial level, conducted through the Ecological Report based on the methodology of the Ecological Footprint.

2. Material and Methods

The assessment of the environmental sustainability of local hazelnut cultivation consisted of three phases: (i) definition of farm models and their production techniques, (ii) assessment of the environmental impact at farm level, (iii) assessment of the environmental impact at the territorial level.

2.1. Definition of Farm Models and Their Production Techniques

The first step to assess the environmental impact of the hazelnut production in the province of Viterbo is the clear delimitation of the hazelnut production area, the modelling of the hazelnut cultivation techniques most frequently adopted in there, and the estimation of their relative weight in terms of cultivated area by farm typologies. Then, by modeling the area cultivated with hazelnut with each technique, the environmental impact at territorial level can be measured.

To define the area that could be considered specialized in hazelnut cultivation, we included all the municipalities where at least the 10% of the agricultural area is cultivated with hazelnut. As shown in Figure 1, the specialized area, located in the area of Monti Cimini (south-east of the province of Viterbo) and mostly near Lake Vico, includes 22 municipalities and extends for 83,300 ha.

Modelling cultivation techniques is quite complex, since there is a great variety of approaches and techniques used on the various farms, in accordance with their structural, economic, and managerial characteristics and also with seasonal trends from one year to another. In this study, to model the cultivation techniques adopted in the province of Viterbo with a sufficient level of representativeness, we opted for the consultation of a panel of experts of the local hazelnut sector. They were asked to define a limited number of typical farm scenarios, indicating the related technical parameters of each scenario. The consultation was carried out in August 2020 applying the Delphi method [26] with a panel of 16 local experts (4 agronomists, 4 farmers, 4 researchers, and 4 agroindustry operators). The first round of questionnaires was aimed at defining the typical farm models of the area. The characteristics proposed to identify the types of farms were: presence/absence of irrigation system; organic/conventional cultivation; full-time/part-time farmer; large/small farm (more/less than 5 ha, respectively).

The same panel of experts defined the production techniques relating to hazelnut cultivation in the Monti Cimini area by completing a second questionnaire which provided the quantification of the following technical parameters for each of the farm model type: yield, mechanical processing, mineral fertilizers, manure, herbicides, plant protection products, number of working days.

The technical parameters defined by the panel of experts were then further validated through the following phases: (1) comparison with Farm Accountancy Data Network (FADN) data; (2) comparison with the reference literature (many articles have been analyzed, but the calculation mainly refers to [23]); (3) consultation with key informants of the territory.

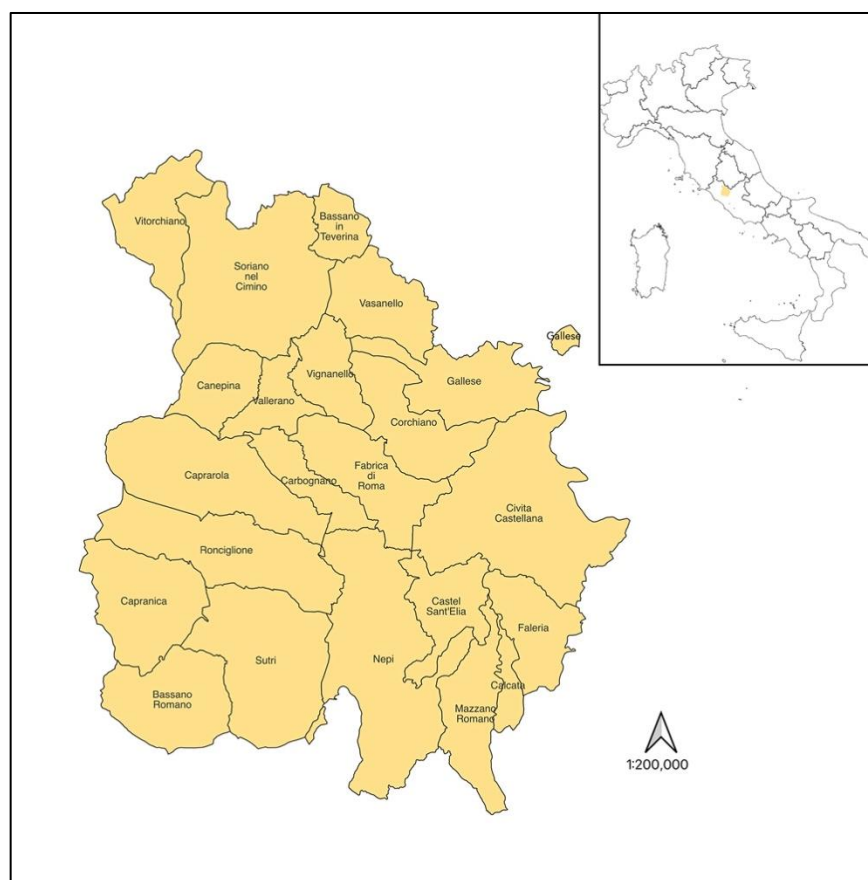


Figure 1. Specialized hazelnut production area.

These steps led to the definition of n farm typologies that are used as a baseline for assessing the environmental impact.

2.2. Assessment of the Environmental Impact at Farm Level

The methodology used to assess the environmental impact of the hazelnut cultivation is based on the calculation of the Ecological Balance (EB), obtained by comparing the BioCapacity (BC) of the cultivation and the Ecological Footprint (EF) generated by its management for each of the n farm models defined. The Ecological Footprint is an indicator capable of measuring human use of environmental resources and is widely used for environmental implications of economic activities based on Daly's first principle of sustainability [27,28]. The EF measures the consumption of natural resources by a certain human activity in a territory and is expressed in global hectares (gha). It indicates how much bio-productive area is necessary to support the human activities carried out. BC is a measure of how much bio-productive area, always expressed in global hectares, is available in a certain territory, considering agricultural areas, pastures, forests, urbanized areas, and water basins. The comparison between these two values is then called Ecological Balance ($EB = BC - EF$) and expresses the difference between the availability and use of natural capital, highlighting a situation of environmental surplus or deficit, which corresponds to a condition of sustainability or unsustainability [29].

The evaluation of the EB of hazelnut cultivation is based on the technical data of representative farms determined as described in Section 2.1. For each one of the n farm typologies, the average of technical coefficients for each category (yield, machinery, labor, fertilizer, pesticide, and water) was calculated. Such coefficients were used to evaluate the supply (BC_i) and the demand (EF_i) of natural capital associated with hazelnut cultivation in the single (i) farm typology. The BioCapacity indicator was calculated considering the

environmental services provided by hazelnut cultivation, which are strictly linked to yield and, hence, to different methods of crop management. This value was calculated as follows:

$$BC = A \times Y_N / Y_W \times EQF$$

where A represents the hazelnut area (set equal to one hectare); Y_N represents the average farm yield (ton/ha); Y_W represents the world yield (ton/ha), available in the FAOSTAT database [30]; and EQF represents the equivalence factor, a standard coefficient which converts a specific world average land area, such as cropland or forest, into global hectares [31].

For each representative farm, the EF value is determined by the sum of two distinct components:

$$EF = EF_{INP} + EF_{OVP}$$

EF_{INP} , linked to the use of production inputs, is (mainly, but not exclusively) associated with greenhouse gas emissions caused by fuel consumption, labor, use of fertilizers and pesticides, water, and energy for irrigation. The conversion of CO₂-equivalent emissions in terms of ecological footprint is based on the net carbon sequestration capacity of forest ecosystems and, in this study, the related coefficient, named Average Forest Carbon Sequestration (AFCS), was considered equal to 0.73 t C ha⁻¹ year⁻¹, as suggested by [2].

EF_{OVP} is based on the difference between the farm crop yield (Y_N) and the yield obtainable in “natural condition” (Y_O) where no crop intervention is provided [32]. This second component is calculated as:

$$BC = A \times k \times Y_N / Y_W \times EQF$$

where k , representing the soil overexploitation caused by the forced increase with respect to natural productivity, is expressed by [32]:

$$k = (Y_N - Y_O) / Y_N$$

For Y_O evaluation, the approach proposed in [33] was applied.

2.3. Environmental Impact at Regional Level

The environmental impact of hazelnut cultivation at a regional level is based on the assessment of a synthetic indicator named EB. This figure is calculated as the difference between the total BC and EF associated with the hazelnut cropping system within the production area identified as explained in Section 3.1. In such a region, the outcome of the Delphi survey reports the presence of $n = 3$ different representative farm models. The unitary values of BC and EF for each one of these models (BC_i , EF_i ; $i = 1 \dots 3$) are multiplied by the total farm area associated with the farming model (S_i ; $i = 1 \dots 3$), identifying the EB value:

$$EB = \sum_{i=1 \dots n} (BC_i - EF_i) \times S_i$$

S_i values were elaborated by starting from agriculture census data and, coherently with the time of the Delphi survey and FADN data, they refer to the year 2020.

To allow a better understanding of the result, the value of the EB, which is expressed in global hectares, can be converted in terms of a real area referring to one of the possible uses of the land provided for by the ecological footprint methodology. We decided to convert the result in hectares of forest, the value of which represents the consumption (if negative) or the supply (if positive) of natural resources expressed in hectares of an “average” Italian forest. This conversion was carried out applying the conversion coefficient represented by the Italian forest yield factor and the equivalence factor [3].

3. Results and Discussion

3.1. Definition of Farm Models and Their Production Techniques

Through the first round of questionnaires submitted to the panel of experts using the Delphi method, we asked for the relevant characteristics for the local hazelnut farms. According to the experts, the presence of an irrigation system is not a relevant characteristic for the local farms; therefore, the other three proposed characteristics were used to define eight possible farm typologies and, among these, the experts identified the most representatives, which are the following three ($n = 3$):

1. conventional farm, with over 5 ha hazelnut groves and a full-time farmer;
2. conventional farm, with a hazelnut grove smaller than 5 ha and a part-time farmer;
3. organic farm, with over 5 ha hazelnut grove and a full-time farmer.

These three typologies together, with 22,300 hectares, represent the entire local hazelnut farming system. Large conventional farms cover 54% of the cultivated area, whereas small conventional farms cover 31% and large organic farms cover 15% (Table 1).

Table 1. Characteristics and representativeness of the farm models of local hazelnut farming.

Cultivation Method	Dimension	Farmer	Typology	Area (%)	S (ha)
Conventional	>5 ha	Full-time	1. Large conventional	54%	12,040
Conventional	<5 ha	Part-time	2. Small conventional	31%	6915
Organic	>5 ha	Full-time	3. Large organic	15%	3345
Total				100%	22,300

Consultation with the panel of experts also made it possible to define the technical parameters for each of the three farm typologies. These technical parameters were then validated through the three steps listed in Section 2.1. At the end of the process, the definition of the analytical technical data sheets of each production process associated with the related farm type, summarized in Table 2, was reached.

Table 2. Technical coefficients of the farm models of local hazelnut farming.

Typology	Yield (t/ha)	Labour Machinery (h/ha)	Labour Special. (h/ha)	Labour Common (h/ha)	Machinery Utilization (h/ha)	N	Fertilizers (kg/ha) P	K	Insecticides (kg/ha)	Fungicides (kg/ha)	Herbicides (kg/ha)
1. Large conventional	2.50	60	30	41	47	115	45	45	1.0	12.4	3.8
2. Small conventional	2.40	100	50	90	86	165	53	29	0.7	15.1	2.7
3. Large organic	1.60	50	25	36	41	68	30	27	0.4	5.5	0.0

The production techniques define essentially differ for the yield; large organic farms have a yield considerably lower than that of the small and large conventional ones for the labor and the use of machines, since small conventional farms have much higher parameters than the other typologies, and for the input, because organic farms record lower values than the other two types and small conventional farms have a particularly high use of some inputs (above all, nitrogen and fungicides).

3.2. Environmental Impact at Farm Level

Using the values reported in the previous Section 2.2, the BC and EF unitary values of the three hazelnut farm typologies are calculated (Table 3). Y_N is represented by the yields shown in the first column of Table 2, whereas in our case, Y_O is equal to 0.89 ton/ha.

Table 3. Ecological balance of local hazelnut cultivation on farm level.

Typology	BC (gha/ha)	EF _{INP} (gha/ha)	EF _{OVP} (gha/ha)	EF (gha/ha)	BC – EF (gha/ha)
1. Large conventional	6.01	1.52	3.87	5.39	+0.62
2. Small conventional	5.77	2.37	3.63	6.00	−0.23
3. Large organic	3.85	1.09	1.70	2.79	+1.06

3.3. Environmental Impact at Territorial Level

With reference to BC and EF of the three farm typologies shown in Table 3, the total EB of hazelnut cultivation within the specialized cultivation area was calculated. For this purpose, the difference between values of BC_i and EF_i referring to one hectare cultivated according to the three techniques (last column of Table 3) was multiplied by the total area falling in the three scenarios (S_i) within the production area (last column of Table 1). Then, these three figures were added, thus obtaining an EB value equal to +9412 gha, as shown in Table 4.

Table 4. Assessment of ecological balance at area level.

Typology	BC – EF (gha/ha)	S (ha)	(BC – EF) × S (gha)
1. Large conventional	+0.62	12,040	+7465
2. Small conventional	−0.23	6915	−1599
3. Large organic	+1.06	3345	+3546
EB			+9412

The positive contributions of EB generated by the production methods associated with larger farms (both conventional and organic) are much greater than the environmental deficit that characterizes small conventional farms. This determines an overall positive environmental balance of the hazelnut cultivation in the specialized production area. Taking as a reference the supply of natural resources associated with an “average” Italian forest, as assessed by the Global Footprint Network, 9412 gha of BioCapacity surplus corresponds to the natural resources made available by 4400 ha of an “average” Italian forest. It follows that the 22,300 ha of hazelnut cultivation located in the 22 municipalities of the specialized cultivation area generate an offer of natural resources equivalent to those provided by an area of 4400 ha of forest.

3.4. Discussion

The results show that the hazelnut farming system in the province of Viterbo has a positive environmental balance, which is equal to 9412 gha. Previous studies aiming at assessing the environmental impact of hazelnut cultivation in the same area used different methods and, therefore, the results are difficult to compare. Coppola et al. [2] evaluated the environmental impact of the conventional and organic farming systems using the Life Cycle Assessment approach, finding that organic cultivation practice has a higher impact in respect to the conventional production. Nera et al. [1], instead, used a participatory approach based on a stakeholder workshop to assess the environmental sustainability of the hazelnut farming system in the province of Viterbo. Their results show a low environmental sustainability of the system due to a perceived excessive use of natural resources. Although comparing these studies with the actual environmental impact of hazelnut farming seems controversial, we believe that this essentially depends on the methodological approach. Our study is the first one that uses the EB tool to assess the impact of hazelnut production. Other recent studies focusing on the evaluation of the sustainability of hazelnut production mainly refer to the Turkish cultivation and propose methods based on indexes of environmental sustainability defined by the researchers [34,35].

Our results are coherent with those emerging from the study carried out by Demiryürek et al. 2018 [34]. The organic production system confirms a better environmental sustainability result than the conventional one. This result can be explained with the evidence that the organic system determines a reduction of the environmental impact, deriving from a lower use of inputs and, in particular, from the use of organic inputs.

Other interesting elements of discussion emerge by examining part-time and full-time farming. In the study by Yildirim et al. 2022 [35], part-time farming makes it possible to obtain more environmentally friendly products thanks to a lower use of chemical fertilizers, thus preserving the soil. Part-time farming is linked to the multifunctionality of the farm; therefore, it is not equal to organic agriculture; however, in this case, it seems possible to argue that these two production methods move in the same direction, as they provide similar results and they both include a more careful management of renewable natural resources, landscape conservation, and biodiversity.

Conventional and organic farming methods have different consequences on the environment. As shown in the results reported in the previous section, organic farming shows better results from an environmental point of view, but using fewer chemical substances that protect the plant from harmful species results in a lower quantity of the product. However, organic farming allows for the preservation of BioCapacity by using energy and natural resources in a more responsible manner and, for the cultivation of hazelnuts, this appears to be linked, to a greater extent, to the dimension of sustainability, as demonstrated in previous studies [36–38].

More generally, the lack of incentives that still exists regarding the application of good agricultural practices requires greater coordination between different actors in order to find solutions that are increasingly compatible with the environment [39].

4. Conclusions

This work intended to assess the environmental sustainability of hazelnut production, with specific reference to the specialized agricultural area in the province of Viterbo, Italy. The aim was to provide a measure of the gap, or the surplus, of natural capital in this system, where the specialization on hazelnut production is very high. The analyses allowed us to understand if the carrying capacity of the agricultural system in the area is able to support the environmental load of the hazelnut production. The methodology proposed is the ecological footprint method, which allows us to compare the environmental impacts of human activities with the supply of natural resources, thus calculating a balance.

Among the three farm typologies defined through the Delphi, the large organic farms show the best environmental performance, with a positive EB of 1.06 gha per cultivated hectare; large conventional farms are also characterized by a positive EB, although to a lesser extent; instead, small conventional farms show a negative EB, suggesting that their consumption of natural resources exceeds the carrying capacity. Looking at the environmental evaluation performed at the territorial level, the overall result is positive, showing that the hazelnut farms of the specialized area make available an amount of natural resources equivalent to 4400 ha of forest. This underlines that the hazelnut agricultural system in the specialized area is environmentally sustainable, and it is even able to provide natural resources for other activities. It is clear that this sustainable condition is due to the presence of large farms that cover more than two thirds of the territory and are managed in a sustainable way. Instead, the contribution of small farms is negative due to the high level of inputs and mechanization.

The results of this study underline the need for a careful measurement of the environmental sustainability of agricultural systems, considering both the consumption and the provision of natural resources by agricultural activities. When this is done, it emerges very clearly that the management of crops at farms exerts a great influence on the result, meaning that the main environmental issue, even in specialized agricultural areas, is how crops are managed. This is also important information for policy-makers, who, at different levels, can promote

sustainable management systems. In order to consolidate the obtained results, further research should focus on the replication of this study in different specialized areas.

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Institutional Review Board Statement: Ethical review and approval were waived for this study after a self-assessment of the ethical issues related to the involvement of human. The experts involved in the Delphi panel did not know the identity of others, nor their personal data were collected as part of the study; informed consent was obtained from all experts involved.

Informed Consent Statement: Informed consent was obtained from all human subjects involved in the study.

Data Availability Statement: Data is available on request due to restrictions of the property of the data.

Conflicts of Interest: The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Tommaso De Gregorio is an employee of Ferrero Trading Lux S.A., which provided financial support to the study.

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