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Environmental sustainability of traditional foods: the case of ancient apple cultivars in Northern Italy

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Abstract

The marketing strategy for traditional food products is often based around their strong connection with their production region and claims of a lower environmental impact due to being grown in the agricultural area for which they were selected. Such traditional foods often comprise ancient cultivars that are unsuitable for large-scale distribution, but generally require less agricultural inputs. However, specific environmental evaluations of ancient cultivars in comparison with commercial cultivars are very rare. This study investigated ancient apple cultivars in Piemonte (Northern Italy) as a case study of traditional food in the framework of sustainable food production.

The production of three representative apple cultivars, Grigia di Torriana, Magnana and Runsé, from Torino and Cuneo provinces was investigated using LCA methodology. In particular, the environmental impacts of these cultivars were compared with those of the commercial cultivar Golden Delicious. The study was performed in accordance with ISO 14040 standards, using the cradle-to-gate approach and the EDIP assessment method. Three different functional units were considered: the production of 1 t of fruit, the growth of 1 ha of orchard, and the earning of €1000 income by the grower. Considering impacts per tonne of product, Golden Delicious had the best environmental performance in most impact categories investigated. However, considering impacts per hectare and €1000 income, the ancient cultivars had the best environmental performance in almost all impact categories. As the impacts of fruit production depended heavily on the functional unit chosen, it is not possible to directly recommend which cultivar should be grown to increase the environmental sustainability. However, the results obtained regarding environmental efficiency and sustainability could be included together with other parameters to make a systemic assessment of different cultivars, which could be useful for policymakers, growers and other stakeholders.

Keywords

Life Cycle Assessment; sustainable agriculture; orchard management; fruit production systems; varietal comparison

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1. Introduction

Until the 1950s, hundreds of different cultivars of apple (*Malus domestica* Borkh.) were grown in Italy, as in many other fruit-producing countries. However, in the 1960s, with the proliferation of commercial cultivars and orchard specialisation, the local germplasm lost importance and began to be forgotten by growers and consumers. Many ancient cultivars were gradually replaced by commercial cultivars and the Italian fruit-growing scene underwent significant change. Now, more than 70% of orchards grow only Golden Delicious. However, the genetic diversity has fortunately been preserved to a large extent, because most genotypes can be found in collection fields (Donno et al., 2012).

While Golden Delicious currently dominates, the ancient apple germplasm of the Piedmont region (Northern Italy) actually consists of about 350 cultivars, 130 of which were recently described by their qualitative, morphological and agronomic traits (Bounous et al., 2006). In particular, orchards where ancient apple cultivars are grown are mostly located in the northern provinces of Cuneo and Torino. In Cuneo, the main production areas are Saluzzo, Verzuolo, Barge, Bagnolo, Manta, Costigliole, Revello, Lagnasco up to Fossano, Busca and Cuneo. In Torino, the more interesting areas are located in Pinerolo and Cavour districts.

Ancient cultivars are characterised by very unconventional quality traits, such as special fruit shape, skin colour, nutritional value and organoleptic traits (such as crispness, juiciness and flavour). For this reason, the ancient cultivars should be preserved in order to maintain biodiversity and also the historical and cultural links that these cultivars represent.

In the past 10 years, various conservation and development programmes studying local fruit germplasm have been carried out in Northern Italy as a cultural initiative, in order to preserve a resource that is closely linked to the natural environment (Bounous et al., 2010). In terms of possible future reintroduction in the culture, a further guarantee of the preservation of unique quality traits can be secured by genetic characterisation, which would allow the creation of

plantations with certified true-to-type trees. The identification, characterisation and valuation of ancient fruit cultivars is becoming fundamental in order to preserve their special qualities and to prevent the loss of precious and useful germplasm (Pretel et al., 2004). Besides the commercial value of local genotypes, the conservation of *Malus* biodiversity is valuable in order to maintain the gene pool of the species and to introduce superior quality traits into apple breeding programmes (Smale and Bellon, 1999; Khanizadeh et al., 2007).

Interest in ancient cultivars of apples from Northern Italy has been growing over recent years, and many research programmes have been carried out to preserve and evaluate *Malus* germplasm with valuable quality features. Indeed, recent studies have demonstrated interesting sensory and nutritional qualities of ancient cultivars from Piemonte (Donno et al., 2012). Since other researchers have already assessed the agronomic performance of these cultivars (Bounous et al., 2006), some of them could be considered by growers who wish to diversify fruit production, exploit local germplasm and increase the diversity of apple cultivars sold on the market. The results of previous studies underline the highly positive sensory traits of ancient cultivars and genetic analysis can further contribute to characterising and preserving the identity of these interesting genotypes. Sensory and nutritional traits of local apple cultivars represent essential information about the product quality and this knowledge could be a useful tool to obtain label certification. In turn, certification and better communication about the quality of traditional varieties could improve the consumption of local products.

Overall, ancient fruit cultivars can be considered a product strongly bound to a specific territory, reflecting the agricultural tradition of the region and the cultural identity of its inhabitants.

The commercial appeal of traditional cultivars is based on their unique quality traits and on claims of their lower environmental impacts due to being the original agricultural land use. Since ancient cultivars are more adapted to the pedoclimatic characteristics of the region in which their traits were selected, they usually require fewer treatments and field operations per hectare of cultivation in comparison with foreign cultivars. However, no previous study has made a specific environmental evaluation of the ancient fruit cultivars and a comparison with commercial apple cultivars. In fact, the assessment method that should be used to evaluate the

environmental performance of fruit production systems is still under debate (Cerutti et al., 2011).

Ignoring rare pioneering studies, it can be assumed that mainstream research on life cycle assessment (LCA) applied to fruit production systems began around 2005. A number of papers were published in 2010 for the 7th International Conference on LCA in the Agri-Food Sector (Notarnicola et al., 2012). However, existing papers applying LCA to fruit production and retailing systems are very diverse in terms of their objectives, system boundaries, functional units and impact categories. The two most widely used system boundaries are cradle-to-gate, in which the environmental impacts are quantified for the production phase including all upstream impacts to the farm gate, and cradle-to-market, which includes all up-stream processes, core production processes and the commercialisation phase. Two particular boundaries are cradle-to-retailer (Sim et al., 2007; Ingwersen, 2010), which also accounts for processing and transport to the distribution system, and cradle-to-use (McLaren et al., 2010), which also accounts for impacts from the consumer phase. Although many authors stress that it is important to consider the nursery in environmental impact assessments (Milà i Canals and Polo, 2003; Cerutti et al., 2012), the lack of data makes this difficult. Another important aspect that has to be considered when the assessment is performed on the entire life cycle of the orchard, and not just on a production year, is the yield in relation to the age of the plantation. Most of the temperate fruit species reach maturity within 2-4 years after establishment of the orchard. Before that age, the yield may be significantly lower (or even zero) because the plants are still too young. This may significantly affect the average yield, and has to be considered. Furthermore, the yield variation between years may be very high, e.g. McLaren et al. (2010) reported a 31% difference between the lowest and highest yields of green kiwifruit over a six-year period, measured as a percentage of the lowest value.

Fruits and processed fruit products may have different quality, nutritional and economic values, and thus it may be difficult to find a relevant functional unit. For fruit products, typical functional units are 1 kg of fresh fruit packed and delivered to the customer or 1 tonne of fruit at the farm gate, although Mouron et al. (2006) compared a land-based and a currency-based functional unit. A land-based functional unit, e.g. 1 ha of orchard, is not frequently used in LCA, partly because land use is not directly a service and does not provide a productive function, but

it can give interesting results. In general, expressing resource consumption or environmental impacts per unit of land used allows evaluation of the impacts of cultivating a certain area. This parameter is also called the impact intensity of a farm (Mouron et al., 2006). The land-based functional unit in fruit production is complementary to the mass-based functional unit because they give different results, and both should be used. Indeed, when considering only impacts per unit area, low input-output systems will have a better ranking in terms of decreased impacts at a regional level, but may create a need for more land use elsewhere, giving rise to additional impacts (van der Werf et al., 2007). Furthermore, as most fruits are rapidly perishable products, quantification of product loss in the supply chain would be needed in order to evaluate the environmental impact of the product actually consumed (Schau and Fet, 2008).

Therefore, the aim of the present study was to conduct an LCA comparing the production of three representative ancient apple cultivars against Golden Delicious production, in order to evaluate differences in their environmental impacts. Specific objectives were to: (I) qualify and quantify the main environmental aspects of ancient apple cultivars in Piemonte in order to establish parameters and reference values for the sustainability of that product; (II) evaluate any statistically significant differences compared with the environmental impact of Golden Delicious production; and (III) contribute to the development of LCA methodology in the agricultural sector, with particular attention to orchard systems.

2. Methods

In order to compare the environmental performance of ancient apple cultivars in Piemonte, the production of three representative cultivars from Torino and Cuneo provinces, namely Grigia di Torriana, Magnana and Runsé, was investigated using LCA methodology. In particular the environmental impacts of the cultivars were compared with those of the commercial cultivar Golden Delicious. Cultivar agronomic requirements may affect sensibly the plantation strategy

and the orchard organization, such as plant density, resulting in different environmental burdens (De Gennaro et al., 2012). Consequently several agronomic traits of the cultivars were collected and the main aspects are summarised in Table 1. In order to consider minor geographical differences, the life cycle inventory (LCI) for each cultivar included the average of three orchards of each cultivar, spread throughout the two provinces. Data regarding orchard structure, agricultural inputs, resource consumption and orchard management practices were obtained directly from the growers, who filled in a questionnaire for the 2011 season.

The study was performed in accordance with the guidelines and requirements of the ISO 14040 standard series and with the cradle-to-gate approach as the basis for the LCI. As advised by other authors (Mila i Canals et al., 2006; Cerutti et al., 2012), in addition to one-year field operations, all the environmental impacts related to the entire lifetime of the orchard were taken into account. In particular, environmental impacts from the establishment stage were considered, evaluated as the common practice of removing previous vegetation, preparing the field for the orchard and the establishment and finally destruction of the orchard, mainly relating to machinery and fuel. Impacts from the production of inputs were considered by dividing flow and stock inputs (Figure 1). Industrial products, such as pesticides, fertilisers and electricity, were accounted for on an annual basis. Stock resources were accounted once per orchard and their environmental impacts were added in proportion to the lifetime of the orchard. The stock resources considered were plastics, steel, piling wood and plants, which were accounted for as the average nursery processes, and resources needed to obtain rootstocks, scions and finally young plants for the quantity of plants per hectare of the given orchard design.

As orchards are multiannual, biological production systems, yield is not constant each year and production has to be modelled for the whole production cycle. Following information provided by growers, the production stage was divided into: Sub-stage (I), which is characterised by low yield production due to young plants; sub-stage (II), which is characterised by high production during the mature stages of the orchard; and sub-stage (III), which is characterised by low production due to ageing plants. The duration of each of the three sub-stages varies according to cultivar. Irrespective of yield, each productive stage includes all one-year field operations, in particular tree management, pest and disease management, soil management, irrigation, weather damage prevention and harvesting. Impacts from pesticide use were

accounted for using Pest-LCI, a pesticide dispersion model developed by Birkved and Hauschild (2006) that considers soil properties and climate conditions at the local production site. Where characterisation factors were not available for the exact pesticide, alternative pesticides with similar chemical and physical properties were chosen for the evaluation. The lack of data about the effects of pesticide residues in crops and groundwater and of spray drift continues to be a matter of general debate (Notarnicola et al., 2012). Environmental exchanges associated with fertilisers were accounted for both during production and as field emissions. Field emissions were estimated through a nutrient balance according to the average physiological requirements of the plants.

The use of different functional units is reported to lead to a more complete understanding of the environmental impacts of a system under study (Martinez-Blanco et al., 2010). Therefore, three functional units were adopted here:

(I) Mass-based: environmental impacts were related to the production of one metric tonne of fruit, regardless of the quality and commercial value of the product. The mass-based functional unit is easy to comprehend and is widely used in fruit sustainability assessments (Cerutti et al., 2011), but carries the problem of evaluating efficiency within sustainability research. Looking only at environmental impacts per unit mass of product evaluates the eco-efficiency of the production but not its sustainability, because efficiency does not necessarily lead to sustainability (Wackernagel and Rees, 1997; van der Werf et al., 2007).

(II) Land-based: the environmental impacts were related to the management of one hectare of orchard. This category is not commonly used in LCA, because land use is not directly a service and does not provide a productive function, but it can give interesting results. Indeed, land-based functional units are gaining importance in comparisons of low input-low output systems with high input-high input systems. The use of a mass-based or a land-based functional unit reflects the perspective addressed by the particular study: the former is used in product-orientated expression of the agricultural production and the latter in land-orientated expression (Hayashi, 2012). Furthermore, the land-based functional unit represents the land management function of agriculture (Nemecek et al., 2011).

(III) Economic-value based: the environmental impacts were related to a particular amount (€) of grower income from wholesale fruit sales. This functional unit is useful because it

integrates product quantity and quality in a single measure (Mouron et al., 2006), but it is strongly influenced by the economic context in which the farm is located and can change significantly from one year to another.

Based on the emissions estimated in the LCI analysis, the environmental impacts were calculated here in the impact categories of the EDIP method. Taking into account results highlighted by Cerutti et al. (2011) in a previous literature review on environmental assessment methods in fruit production systems (, 2011), the present study used impact categories that quantify environmental impacts on ecosystems rather than on resource consumption or human toxicity, with particular attention to global warming, eutrophication and acidification potential.

Production data were collected from multiple farms with the same cultivar and these farms were used as replicates in statistical analyses. Each orchard was considered a replicate of an experimental design for the analysis of variance (ANOVA) and the weighted impact potential resulted from the assessment were analysed within each functional unit. Tukey's post-hoc test was used when the ANOVA identified significant differences ($P < 0.05$). The statistical software package SPSS 18.0 was used for this analysis. The statistical analysis was applied only to the weighted results in order to evaluate the statistical significance of the overall environmental ranking.

3. Results

The impacts of the four production systems are presented in Tables 2-4 according to the functional unit used. Considering impacts for 1 t product (Table 2), the Golden Delicious cultivar showed the best environmental performance in all environmental categories studied except ozone depletion potential. Within other impact categories, important differences emerged. The ancient cultivars showed on average 33% higher environmental impacts in nutrient enrichment potential, 20% higher in acidification potential and 17% higher in global warming potential in relation to Golden Delicious. However, the results were the opposite considering the impacts for 1 ha (Tables 3) and €1000 income (Table 4). According to these functional units, the ancient cultivars had the best environmental performance in almost all the impact categories studied.

The impacts for Golden Delicious production per ha of orchard were on average 24% higher in global warming potential, 22% higher in acidification potential and 14% higher in nutrient enrichment potential in relation to the ancient cultivars.

Considering the contribution of different substances it is possible to verify that different emissions play different roles in the considered impact categories. In global warming potential, carbon dioxide is the most important emission, covering from 85.54% to 87.46% of the CO₂ equivalents among all the cultivars. Other major contributors in this category are nitrous oxides (11.16% to 12.04%) and methane (1.73% to 1.87%). In nutrient enrichment potential, nitrogen oxides, as a group, is the most important emission, with an average 66.34% of the NO₃⁻ equivalents among all the cultivars. Other major contributors in this category are nitrate (13.31%), nitrous oxide (10.41%) and ammonia (9.46%). Also in the acidification potential impact category, the group of nitrogen oxides have the biggest contribution (average 71.36% of the SO₂ equivalents among all the cultivars), followed by sulphur dioxide (16.59%), ammonia (10.13%) and sulphate (1.82%). For any impact category, significant differences in the share of each substance were found among the studied cultivars.

In order to assess the contribution of the different impact categories compared with the impacts that an average person would otherwise be responsible for, the results were normalised according to the EDIP method with reference to the total impacts of activities in Europe. The normalised results are expressed in units of person equivalents (PE), which corresponds to the impact one person has in a given category. For all three functional units studied, the dominant impact categories were similar to those commonly identified as important in agricultural LCAs, namely global warming potential (most important), nutrient enrichment potential and acidification potential (Figures 2-4).

Furthermore, in order to compare the total environmental impacts of the four cultivars against each other, weighting was performed in accordance with EDIP (1997). In this method, political targets are used to scale the importance of the different impact categories against each other. The units in which the results are expressed are person equivalents according to the target given for the future (PET). Statistical analysis on the weighted results calculated for each individual replicate revealed significant differences using the mass-based functional unit ($P=0.0165$) and the land-based functional unit $P=0.0174$. No statistically significant differences

were found using the income-based functional unit ($P=0.0879$). The results of Tukey's test are shown directly in the respective diagrams. The results per ton of fruit (Figure 5) showed that Golden Delicious had the best overall environmental performance, 0.054 PET, compared with an average of 0.68 PET for the ancient cultivars. According to the Tukey test, the environmental performance of Golden Delicious was significantly different than that of the ancient cultivars .

The results per ha of orchard (Figure 6) showed the opposite situation, i.e. Golden Delicious was the cultivar with the poorest environmental performance, 2.199 PET, compared with an average of 1.756 PET for the ancient cultivars. In this case the Tukey test distinguished three statistically different groups: (I) Golden Delicious, (II) Grigia di Torriana and (III) Magnana and Runsé. Considering both methods, the Golden Delicious cultivar was statistically distinguished from the ancient cultivars, regardless of their group setting.

The impact results related to €1000 grower income (Figure 7) were almost the same for all cultivars, with values ranging from 0.103 PET for Runsé to 0.109 PET for Golden Delicious. Accordingly, the statistical analysis did not find any significant differences.

4. Discussion

The results of the present study highlight an important issue which is often encountered in LCAs on food, namely that the use of different functional units may lead to different results (Notarnicola et al., 2012). In the case study presented here, the environmental performance of Golden Delicious moved from best to worst depending on the functional unit used. This effect was due to the high quantity of this fruit produced per hectare. In general, the environmental impacts from emissions and resources consumed in production are divided by the total amount of commercial product, without taking into account the environmental impact of the total production system. On the other hand, the method of impacts per ha of orchard (which is not an output of the production system) considers the actual quantity of emissions and resource depleted per ha and for the whole system. It is clear that the use of one or the other functional unit addresses different research questions. The impacts per ton of product define the

environmental performance of a production system, and indicate what should be achieved when looking for the most environmentally efficient production system. In contrast, the results of impacts per ha of orchard define the total environmental impact of a system, and should thus be used when investigating fruit production systems in sensitive areas in which a reduction in target emissions is required (e.g. nitrate leaching). Assessment using the economic performance of the farm is more similar to that using the mass-based functional unit, because it highlights environmental impacts related to the production of a specific amount of income. The environmental efficiency of the system is assessed, but considering the potential of the system to generate money (a social aspect) instead of food (a biological aspect). However, the economic functional unit can also be considered to be an integrated measure of quantity and quality. The assessment conducted using the income-based functional unit appears to be strongly bound to the social dimension, because the possibility of generating income is strongly related to markets and consumer preferences, and thus it seems to be less objective and weaker from a scientific point of view. Nevertheless, it must be borne in mind that the biological potential of an orchard to produce fruit is strongly related to several agronomic factors, such as management techniques and production procedures, which are related to the knowledge and economic availability of the grower. Thus this aspect is also linked to the social dimension and can be considered as significant as income-based environmental assessment.

Golden Delicious can be considered to be the most efficient genotype from an environmental point of view, as it had significantly lower impacts per ton of fruit than the ancient cultivars. Runsé, Griglia di Torriana and Magana showed similar environmental performance and can be statistically considered as one single group. From the agricultural point of view, the difference in performance between Golden Delicious and the ancient cultivars represents the increasing efficiency of production obtained by breeders in the selection process occurring over decades. The breeding done on the Golden Delicious germplasm means that this commercial cultivar can produce more fruit than ancient cultivars for a given quantity of agricultural inputs. Considering just the global warming potential as an example, emission of 1 kg CO₂-equivalents in a Golden Delicious orchard produces 6.10 kg of apples and in an orchard of ancient cultivars produces on average 5.18 kg of apples.

On the other hand, when considering the whole environmental impact of the orchard, i.e. looking at results per hectare cultivated, the findings are the opposite. Ancient cultivars have the smallest impact on the natural system in which they are located. Continuing the example with the global warming potential, in this case emission of 1 kg of CO₂-equivalent in an orchard of ancient cultivars represents on average a cultivated area of 2.03 m² and in a Golden Delicious orchard only 1.52 m². Thus ancient cultivars represent smaller impacts per unit of cultivated land, and according to a strong sustainability framework (Goodland and Daly, 1996) in which maintaining ecosystem services is more important than production, ancient cultivars would be considered more environmentally sustainable than modern cultivars.

The environmental performance assessed by the income-based functional unit produces yet another scenario: Golden Delicious has the same environmental ranking as the ancient cultivars. This result is the effect of the differences in price between the two products. The higher economic value of the ancient cultivars is balanced by the minor quantity of fruit produced, and thus the overall farm income per hectare is potentially the same. Using this method, we have to consider that the same cultivars in another region would probably show completely different performance due to the absence of a market because of different consumer choices.

Since the impacts of fruit production depended heavily on the functional unit chosen, in this case study it was impossible to determine what kind of apple cultivar should be grown to increase the environmental sustainability of production. However, the results obtained on environmental efficiency and sustainability may be included with other parameters, such as fruit quality, adaptiveness of the cultivation, effects on landscape properties and preservation of local heritage, in systemic assessments of different cultivars, which could be useful for policymakers, growers and other stakeholders.

5. Conclusions

This study showed that different functional units used in LCA actually address different research questions, so the scope of the research has to be carefully described. The results

confirmed the better environmental performance of modern agricultural cultivars, in this case recent apple germplasm (Golden Delicious) compared with ancient cultivars. In the pedoclimatic conditions of the Piemonte region of Northern Italy, Golden Delicious produced higher fruit yields than ancient cultivars per quantity of inputs. However, in terms of sustainability, the ancient cultivars represented lower impacts per unit of cultivated land. Thus according to a strong sustainability framework (Goodland and Daly, 1996) in which maintaining ecosystem services is more important than production, ancient cultivars can be considered more environmentally sustainable than modern cultivars. Furthermore, although in this case study an income-based functional unit gave no statistically significant differences, it proved useful for ranking the cultivars from an environmental point of view considering both quantity and quality of product. Further studies should evaluate whether similar results are obtained on comparing systems with similar properties, such as conventional and organic production.

Besides methodological aspects in ranking cultivars following sustainability criteria, it is important to note that sustainability is itself a political construct. Several aspects contribute simultaneously, but with different priorities, to policy making in agriculture and land management, therefore different results may occur even having sustainability as the same target. Indeed, concerning current pressures on the climate system, on land requirements and on global food production the golden delicious variety could well be given political priority, according to the results of this study. On the other hand considering resilience as a keystone in achieving sustainability, more valuable and pressing policies for planting and preserving ancient cultivars should be considered. At the moment, the two scenarios seem to be in open contrast and this situation leads to unavoidable trade-offs between choosing protection of genetic and traditional heritage and wider developments in global agri-food systems.

In conclusion, as the impacts of fruit production depended heavily on the functional unit chosen, it was impossible to determine what kind of cultivar should be grown to increase the environmental sustainability of production. However, the results obtained on environmental efficiency and sustainability may be included with other parameters, such as fruit quality, adaptiveness, effects on landscape properties and preservation of local heritage, in systemic assessments of different cultivars.

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Table 1

Main agronomic properties of the cultivars studied

Characteristics	Golden Delicious	Grigia di Torriana	Magnana	Runsé
Origin	Clay County. West Virginia (United States)	Barge, Cuneo (Italy)	Bibiana, Torino (Italy)	Cavour, Torino (Italy)
Vigour	medium-low	medium-low	medium	high
Flowering period	Early (2nd week of April)	Early (2nd week of April)	Early (2nd week of April)	Early (2nd week of April)
Harvest period	Early (end of September)	Medium-late (end of October)	Late (2nd week of November)	Late (2nd week of November)
Orchard design (cm)	400-450 * 80-100	450 * 150	450 * 180	500 * 200
Plants per hectare	2200-3000	1450	1230	1000
Yield (t/ha)	40	25	23	20
Wholesale fruit price in 2011 (€/kg)	0.40-0.80	0.60-1.00	0.60-1.00	0.60-1.00

Table 2

Characterisation results using the mass-based functional unit: 1 t of product at the farm gate

EDIP 1997. Env. imp. eval. categories	Golden	Grigia T.	Magnana	Runsé
Acidification potential (kg SO ₂ -eq)	0.775	0.954	0.971	0.945
Global warming potential (kg CO ₂ -eq)	163.882	203.89	192.874	196.5484
Nutrient enrichment potential (kg NO ₃ -eq)	1.581	2.304	2.284	2.304
Ozone depletion potential (kg R11-eq)	2.31E-07	1.67E-07	1.79E-07	1.65E-07
Photochemical oxidant potential (high NO _x) (kg ethene-eq)	0.040	0.042	0.042	0.045
Photochemical oxidant potential (low NO _x) (kg ethene-eq)	0.038	0.040	0.043	0.041

Table 3

Characterisation results using the land-based functional unit: 1 ha of orchard

EDIP 1997. Env. imp. eval. categories	Golden	Grigia T.	Magnana	Runsé
Acidification potential (kg SO ₂ -eq)	31.005	25.725	23.190	23.110
Global warming potential (kg CO ₂ -eq)	6555.303	5554.788	4775.942	4540.819
Nutrient enrichment potential (kg NO ₃ -eq)	63.269	60.591	50.092	51.454
Ozone depletion potential (kg R11-eq)	9.24E-06	5.05E-06	4.13E-06	4.21E-06
Photochemical oxidant potential (high NO _x) (kg ethene-eq)	1.639	1.238	1.115	1.081
Photochemical oxidant potential (low NO _x) (kg ethene-eq)	1.537	1.120	0.952	0.978

Table 4

Characterisation results using the income-based functional unit: €1000 of grower income

EDIP 1997. Env. imp. eval. categories	Golden	Grigia T.	Magnana	Runsé
Acidification potential (kg SO ₂ -eq)	1.550	1.413	1.427	1.481
Global warming potential (kg CO ₂ -eq)	327.7651	305.208	293.904	291.078
Nutrient enrichment potential (kg NO ₃ -eq)	3.163	3.329	3.082	3.298

Ozone depletion potential (kg R11-eq)	4.6E-07	2.7E-07	2.5E-07	2.6E-07
Photochemical oxidant potential (high NO _x) (kg ethene-eq)	0.081	0.068	0.068	0.069
Photochemical oxidant potential (low NO _x) (kg ethene-eq)	0.076	0.061	0.058	0.062

Figure description

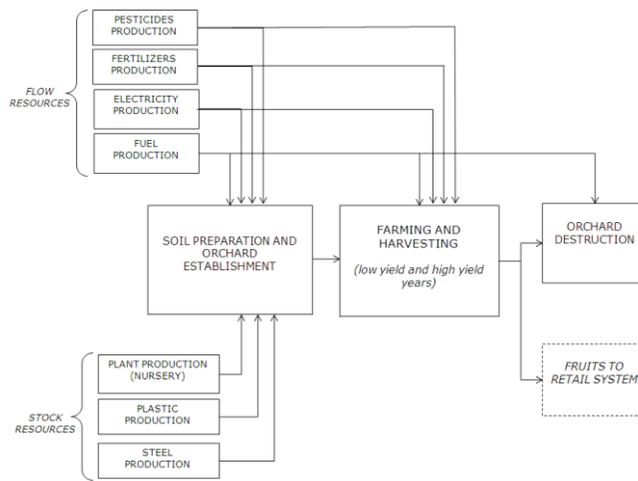


Figure 1. System boundaries of the study. Dotted line box indicates processes not included in the assessment.

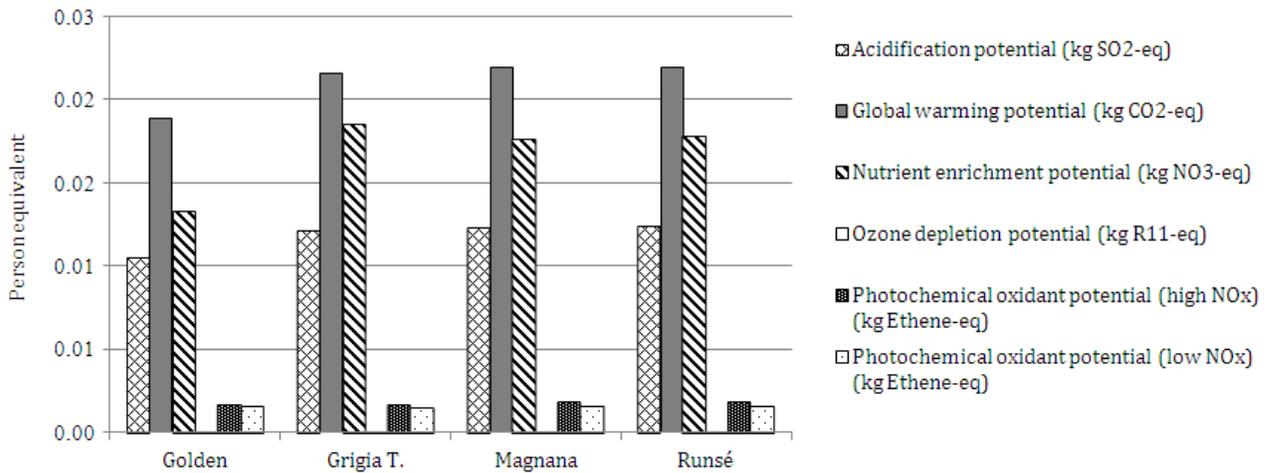


Figure 2. Normalised impact potentials using the mass-based functional unit: 1 t of product at the farm gate.

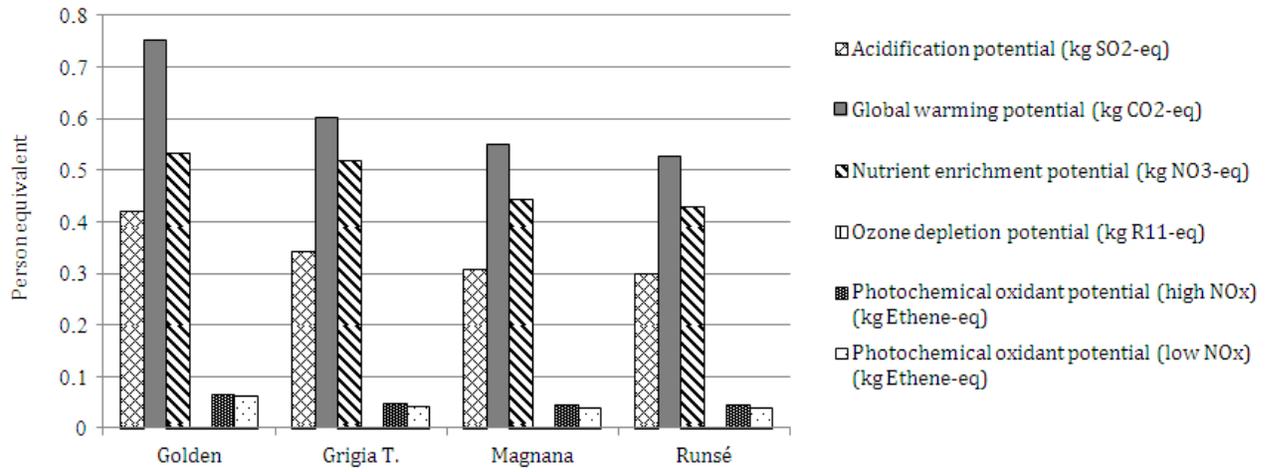


Figure 3. Normalisation results using the land-based functional unit: 1 ha of orchard.

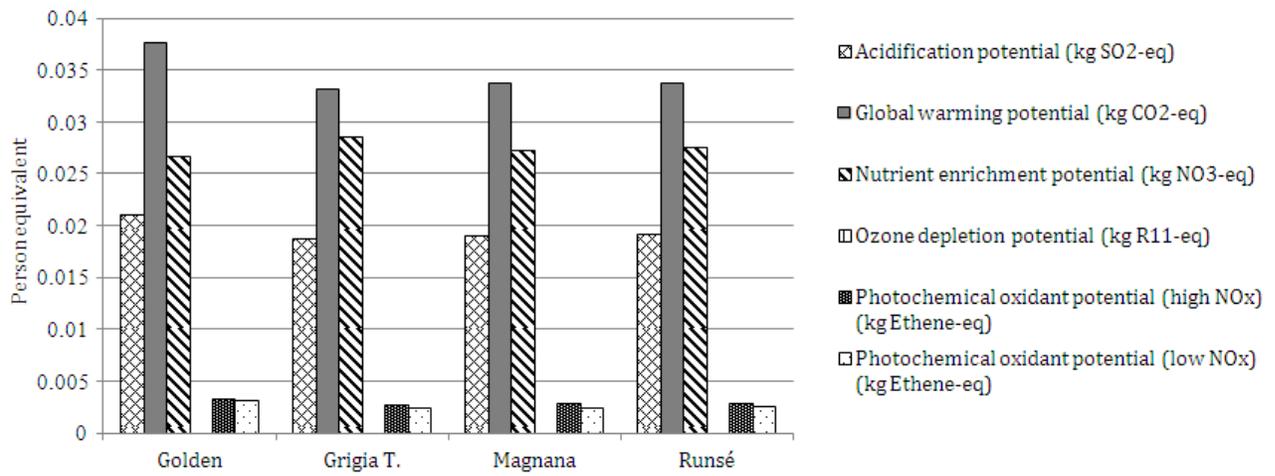


Figure 4. Normalised impact potentials using the income-based functional unit: €1000 of grower income.

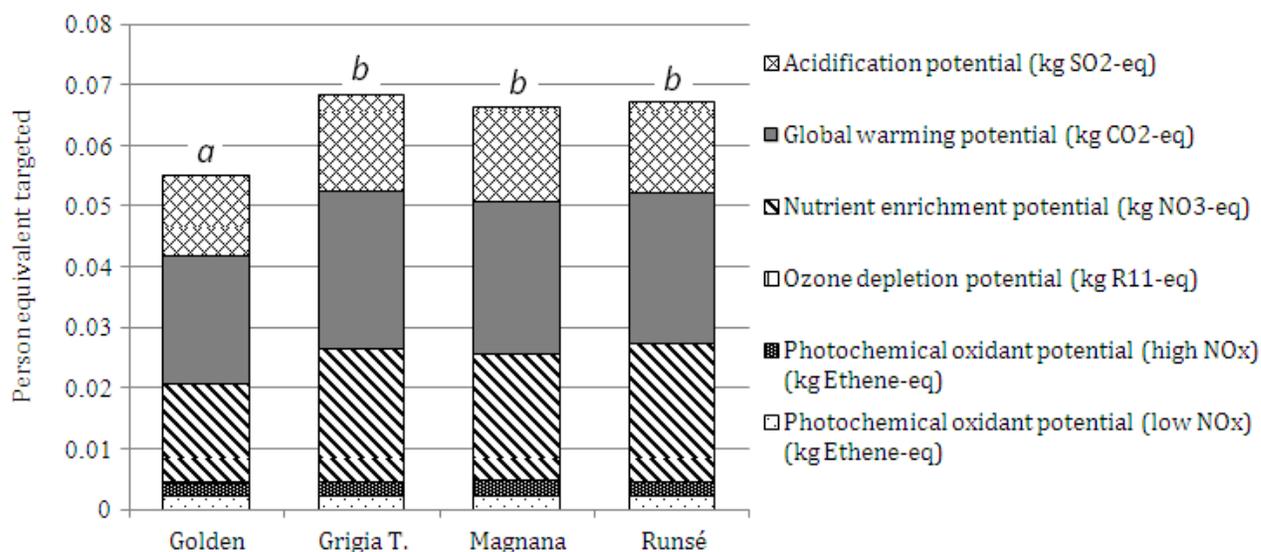


Figure 5. Weighted impact potentials using the mass-based functional unit: 1 t of product at the farm gate. Different letters represent statistically different groups according to the Tukey test ($P < 0.05$)

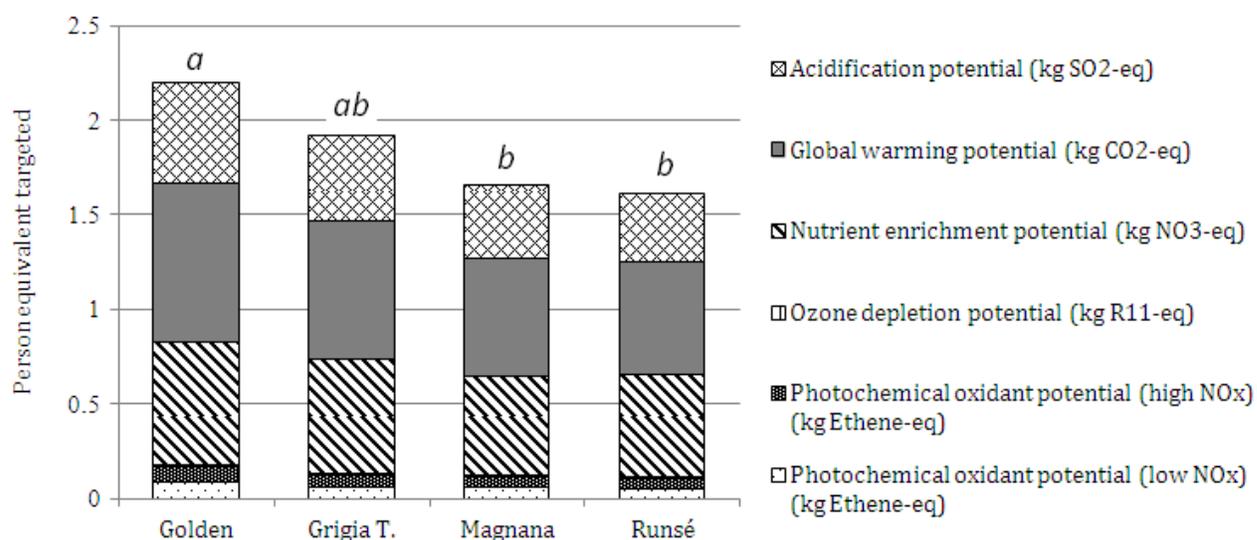


Figure 6. Weighted impact potentials using the land-based functional unit: 1 ha of orchard. Different letters represent statistically different groups according to the Tukey test ($P < 0.05$)

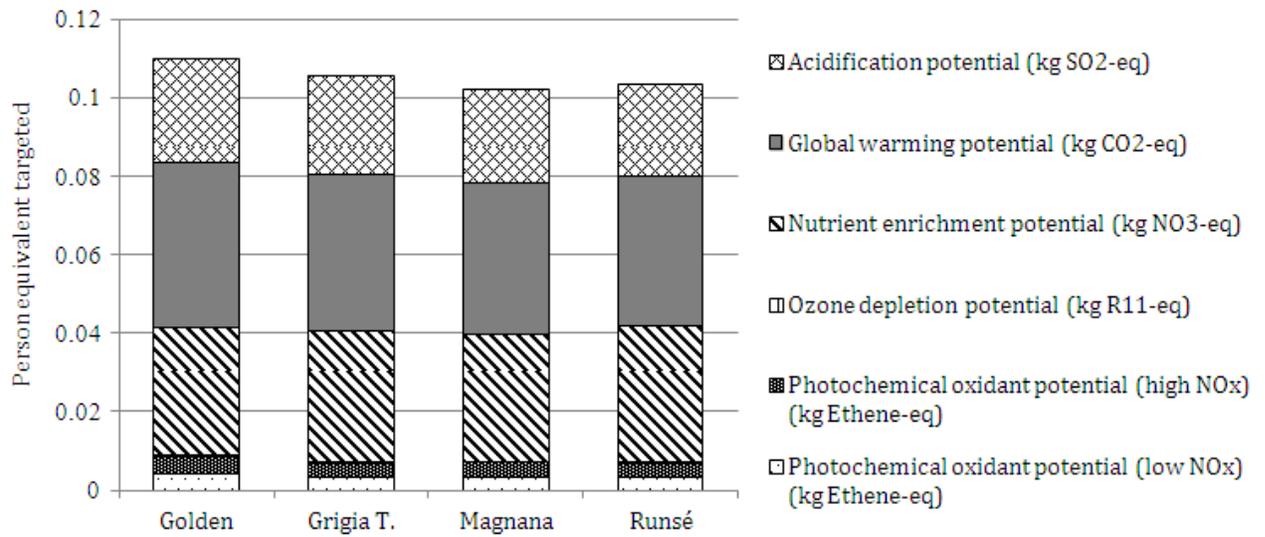


Figure 7. Weighted impact potentials using the income-based functional unit: €1000 of grower income. No statistically significant differences were detected ($P>0.05$)