Water Footprint of Food Quality Schemes

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Abstract

Water Footprint (WF, henceforth) is an indicator of water consumption and has taken ground to assess the impact of agricultural production processes over freshwater. The focus of this study was contrasting non-conventional, certified products with identical products obtained through conventional production schemes (REF, henceforth) using WF as a measure of their pressure on water resources. The aim was to the show whether products that are certified as food quality schemes (FQS, henceforth) could also incorporate the lower impact on water among their quality features. To perform this comparison, we analysed 23 products selected among Organic, PDO and PGI as FQS, and their conventional counterparts. By restricting the domain of analysis to the on-farm phase of the production chain, we obtained that that no significant differences emerged between the FQS and REF products. However, if the impact is measured per unit area rather than per unit product, FQS showed a significant reduction in water demand.

Key Words: agricultural production, crop water requirement, evapotranspiration, irrigation, yield, water footprint.

1. Introduction

In the last years, consumers' attitude has been gradually including environmental issues among the priorities for selecting food products. This tendency is witnessed by the growing larger of the market of organic products, which, historically, have taken ground mainly because of the real and perceived risk associated with use of chemical in agriculture and that of new genetic varieties (Magkos et al. 2012; Shafie and Rannie 2012; Tregear et al. 1994,). Other products that traditionally have encountered consumers' appreciation are those labelled as Protected Designation of Origin (PDO, henceforth) and Protected Geographical Indication (PGI). The former are products that have the strongest links to the place in which they are made and every part of the production, processing and preparation phases take place in that specific region. The latter are products for which the relationship between the specific geographic region and the name of the product, where a particular quality, reputation or other characteristic that is essentially attributable to its geographical origin is emphasized. For most products, at least one of the stages of production, processing or preparation takes place in that region. (https://ec.europa.eu/info/food-farming-fisheries/food-safety-and-quality/certification/quality-labels/quality-schemes-explained, Grunert and Aachmann 2016).

More recently the debate around sustainability has contributed to broaden environmental requirements that agricultural production should incorporate, and water scarcity is one of the most prominent (Brauman et al 2013; Tilman et al. 2002). The present production patterns are inexorably raising the demand for water to grow food, supply industries and sustain urban populations. In addition, climate alteration conspires to make the problem of water scarcity worse (Gosling and Arnel 2013; Vörösmarty et al. 2000). Water demand is one of the key issues for the years to come as it is demonstrated by the interest that governments, corporations and communities show about the future availability and sustainability of water supplies (Turton et al. 2007).

During the last twenty years, researchers have developed a number of metrics to characterize, map and track water scarcity Examples are the ratio of population size to the renewable water supply (Abughlelesha and Lateh 2013) and the ratio of water withdrawals to the renewable supply (Doreau et al. 2012). These water scarcity indicators have highlighted the mismatch between water availability and water demand, and have contributed to focus attention over water scarcity (Pollard and du Toit 2005; Suweis et al. 2013).

If global indicators have the merit to present a whole system perspective, to effectively counteract freshwater consumption in food production baseline knowledge of the intensity at which this precious resource is used in specific production processes is needed. In this work we present the results of an investigation conducted on a sample of 23 of products, 10 PGI, 6 PDO and 7 Organic. Its focus was on water demand of these products compared with that of analogous products obtained through conventional production processes. The aim of the research was to highlight whether the production processes that characterise Organic, PDO and PGI products also imply a reduced intensity of water use in respect to conventional productions. Contrasting a rather high number of products offer an opportunity to initiate an overall assessment of the different impact on water resources of different farming system going beyond the single product comparison.

Over the years in the agricultural sector numerous studies applied WF. According to Lovarelli, Benacelli, and Fiala (2016) the most part of these studies aimed at quantifying the WF for specific types of crop, with focus on factors that affect the indicator (e.g. climate conditions). Interest was devoted to the calculation methodology (e.g. Life Cycle Assessment or Water Footprint Network approaches) and the comparison with other types of footprint (e.g. Carbon Footprint). The WF was used to highlight differences about the impact on water resource of conventional and organic farming (Borsato et al. 2020; Palhares and Pezzopane 2015; Schäfer and Blanke 2012). However, such comparisons considered only one product in the two different schemes of production. This paper is the first attempt, to make an overall assessment of different farming systems in terms of water consumption because it extends the comparison to a rather large set of products

The analysis was conducted by contrasting the WF of FQS and their REF counterparts.WF is expressed as water volume per unit product (usually m^3/ton or litre/kg, Hoekstra et al. 2011), and provides an estimate of how much water is needed to complete the entire production cycle up to the final product. However, to know the pressure on water resources of agricultural products it is also useful to have a measure of the intensity at which water is used in agricultural practices and for the sample of the 23 couples of products we also computed the water consumption per unit area (m^3/ha), which we conventionally called Water Impact (WI, henceforth). Estimating water consumption per unit area may provide a preliminary assessment of the intensity of water use in the field and can support decisions associated to crop practices in relation to land use and water availability at the regional and local level (Wichelns 2001).

This research was conceived to investigate whether the particular production process that characterize FQS has beneficial implications also on water demand Because the paper embraces several issues, a brief summary of its structure is given here below. The methods illustrate first a strategy of implementation in which specific methods and selection of approaches are defined. A brief description of the methods for WF computation follows: water footprint network approach, life cycle method and per hectare impact. A section dedicated to data collection and approximations describes the type of data used and approximations applied for data completion. A section dedicated to data structure and the statistical analysis closes up the method section. Results, discussion and conclusions complete the paper layout.

2. Material and methods

2.1 Strategy of implementation

Two main approaches for the assessment of the WF exist in the literature (McGlade et al. 2012; Postle et al. 2012): (1) the volumetric approach, developed by the Water Footprint Network (WFN, Hoekstra et al., 2011) and (2) the Life Cycle Analysis approach as developed by the LCA community (Pacetti et al. 2015). In this paper the two methodologies have been used to compute different contributions that, overall, make the on farm WF for the 23 selected products. On farm WF estimates water consumption for the part of the production chain that occurs in the farm.

The WF comprises three fractions: green, blue and grey (Hoekstra et al. 2011). The green WF accounts for consumption of the rainwater through the process of evapotranspiration by the plants; the blue WF refers to the consumption of surface and groundwater along the supply chain of a product; the grey WF accounts for pollution and is defined as the volume of freshwater that is required to assimilate the load of pollutants given the natural background concentrations and the existing ambient water quality standards for any of the pollutant considered (e.g. pesticide active principles, nitrogen in fertilizers).The on-farm phase contributes to all the three forms of the WF.

2.2. Methods

2.2.1 WF Methodology: The Water Footprint Network Approach

The WNF approach was applied to estimate the green and the blue WF. The software CROPWAT 8.0 (http://www.fao.org/land-water/databases-and-software/cropwat/en/), executed the computations. It is a Decision Support System (DSS) that was developed by the Food and Agriculture Organization of the United Nations (FAO) for planning and the management of irrigation projects. While we address the reader to the technical literature for the details of calculation (Allen et al. 1998; Hoekstra et al. 2011; Steduto et al. 2012) we provide here below some basic concepts that summarize the rationale behind the calculation procedure. The key parameter is crop evapotranspiration. It is the amount of water required to compensate for the water loss through evapotranspiration of the cropped field.

First, CROPWAT 8.0 computes the reference (standard) evapotranspiration ET_0. It does it through the Penman-Monteith method (see Allen et al. 1998 for details, equations and parameters) which is maintained as the sole standard method for the computation of ET_0 from meteorological data. The set of data needed comprises: i) solar radiation (ten-day or monthly average of daily net radiation computed from the mean ten-day or monthly measured shortwave radiation or from actual duration of daily sunshine hours); ii) air temperature (ten-day or monthly average daily maximum $Tmax$ and average daily minimum temperature $Tmin$); iii) air humidity (ten-day or monthly average) and iv) wind speed (ten-day or monthly average of daily wind speed data measured at 2 m height).

After processing meteorological data, CROPWAT returns the value of ET_0 which is the evapotranspiration of a reference surface. It represents the rate at which water would be removed through evaporation from the soil and plant surface of a grass reference crop,

ET_0 is completely determined by meteo-climatic conditions. However, it does not account for the specific evapotranspiration of any given crop. This process is affected by canopy properties and aerodynamic resistance which change from one crop to another. Such features, for any specific crop, are integrated into the crop coefficient Kc which multiplies the reference evapotranspiration to yield effective crop evapotranspiration $ETc = Kc \times ETo$.

Kc is a critical parameter, as it changes in time depending on the growth phase of the crop plants. As crop develops, the ground cover, crop height and the leaf area change as well as soil evaporation, with effects on evapotranspiration. The procedure identifies four distinct growth stages: initial, crop development, mid-season and late season. The technical documentation (Allen et al. 1998; Smith 1996,) makes Kc values for the growth stages available for most of the crops. From this databank we extracted the Kc values for initial, mid-season and harvest time of the selected crops, that we fed to CROPWAT. Other input data included the duration time (in days) of each growth phase (initial, crop development, mid-season and late season), that we obtained from each case study conductor. The program renders a series of Kc values covering the entire growing season. Multiplying these values by ET_0 the software returns the ET_c values for the different periods of the crop growing season. These values quantify the overall water demand that a crop require to compensate for water loss through evapotranspiration (Crop Water Requirement, Allen et al. 1998).

From ET_c CROPWAT renders the so-called green evapotranspiration ET_{green}. which is used to calculate the green WF. Evapotranspiration may or not be compensated for by rainfall. When precipitations are in excess this compensation occurs and $ET_{green} = ET_c$. If precipitations are scarce, then water available for crop evapotranspiration is less than ET_c . In this case ET_{green} coincides with the amount of rainfall. So ET_{green}coincides with the minimum between effective rainfall $\left(P_{eff}\right)$ and the crop water evapotranspiration (ET_c):

$$ET_{green} = min(ET_c, P_{eff}) \quad (1)$$

When ET_c is higher than the effective precipitation, evapotranspiration requirements must be fulfilled by irrigation and the green evapotranspiration corresponds to the effective precipitation, which all goes to satisfy plant water needs. In this latter case irrigation is necessary for crops to grow optimally. This irrigation requirement (IR) is equal to the difference between crop evapotranspiration and effective rainfall and determine the blue evapotranspiration (ET_{blue}):

$$ET_{blue} = IR = max(0, ET_c, -P_{eff}) \quad (2)$$

It is the fraction of evapotranspiration that is satisfied by irrigation. When the effective rainfall is greater than the total crop evapotranspiration $ET_{blue}$is equal to zero. The blue and green crop water requirements (ET_{blue} and ET_{green}, respectively) are then transformed into blue and green water use $(CWU_{blue,green})$ by multiplying their values by 10, which converts water depths in millimetres into water volumes per land surface in m^3/ha. Finally, the two fractions of the WF are obtained through

$$WF_{green,blue} = \frac{CWU_{blue,green}}{Y} \quad (3)$$

in which Y is the crop yield.

The grey WF was computed according to Franke et al. (2013). In particular, we followed the Tier 1 approach, which allows a first estimate of the amount of a given substance entering the groundwater or surface water system when spread on or into the soil. It however does not describe the different pathways of a chemical substance from the soil to surface or groundwater and the interaction and transformation of different chemical substances in the soil or along its flow path. This second step was impossible to apply due to the difficulty to construct specific computations for every single product. Tier 1 is essentially based on the formula

$$WF_{grey} = \frac{[(\alpha\ Appl/(C_{max} - C_{nat}))]}{Y} \quad (4)$$

in which the variable $Appl$ represents the quantity of chemical substances applied on or into the soil (in mass/time, artificial fertilizers, manure or pesticides); α is the leaching-runoff fraction, defined as the fraction of a given chemical reaching freshwater bodies. This product assumes that a certain fraction of the applied chemical substance reaches the ground- or surface water (Franke et al. 2013). The terms C_{max} and C_{nat} stand respectively for the maximum acceptable concentration and the natural concentration in a receiving water body. The former is the maximum acceptable concentration of a given pollutant and it is defined through the water quality standards that legislation establishes for a given territory. The latter is the concentration in the water body that would occur if there were no human disturbances in the catchment.

We obtained the WF for vegetal productions simply from the straightforward application of the above methods of calculation. For animal products (meet, cheese, and so forth) the computation required further steps. First we computed the WF of the crops composing the diet of the animals, as illustrated above. The three fractions of the WF are given in m^3 /ton. Then e calculated the overall amount of each crop that was consumed by each animal ($ton/ind. \times year$). We multiplied the WF values of each crop by the amount of that crop that enters the animal diet to obtain the WF associated to the fraction of the crop consumed by each animal. We extend this computation to all crops in the diet. The summation of these values yields the total water requested by the individual in the unit time ($m3/ind \times year$). We then needed to convert this total water in a per unit product measure. To this end we used production coefficients. For example, in the case of cheese production the amount of water required by each individual (cow) per unit time becomes water per unit product considering the amount of milk produced by each animal in the unit time, the lactation period and the product ratio cheese/milk (how much cheese is produced by a unit weight of milk).

2.2.2 *WF Methodology: The Life Cycle Approach*

This approach was applied to compute the water consumption due to all the activities that are essential for production, from the field to the stable. In the paragraph dedicated to data structure we provide a detailed description of the items that we included in the WF computation. The input data were collected by the case study conductor or derived from national accountings or from the literature.

For the impact analysis (i.e. water consumption to obtain a given output) we used the Ecoinvent 3.1 database (https://www.ecoinvent.org/), in which specific processes and associated elementary flows are stored for a vast array of the products. In particular, the dataset provided a complete list of all environmental flows related to the provision of the functional unit of each item. To give an explanation of the procedure, consider an agricultural production which requires a specific amount of mineral nitrogen (Kg/ha). Because Ecoinvent includes in its databank a process that produces fertilizers with a mean content of Nitrogen equal to 24,8%, the amount of nitrogen applied to grow a given crop (primary data) is transformed in the overall quantity of fertilizer of which the primary data represents the 24,8%. This result must be further divided by the yield to get the amount of fertilizer for one unit output (functional unit, which is the reference quantity). The software Open LCA thus returns the amount of water needed to manufacture the amount of fertilizer that contains the quantity of mineral nitrogen corresponding to the primary data.

The same applies, for example, to electricity consumption. The amount consumed in a production process is the primary data that is associated to a process of electricity production in Ecoinvent 3.1. It is possible to assign a given electricity mix from which the amount of electricity used (primary data) is obtained (e.g. Italian energy mix for production located in Italy). This procedure yields the amount of water needed to produce that quantity of electricity.

2.2.3 *WF Methodology: The per hectare Impact*

According to the recommendations of the WFN, we computed WF as the amount of water used per unit of final product. Nonetheless, we were interested in estimating how much water each product requires per unit surface (ha). We kept this estimate separate from the WF and we called it Water Impact (WI), which we divided as for the WF in green, blue and grey contributions. WI is something different form the WF, both conceptually and operationally. The calculation in fact is much simpler in the case of animal products because it does not include crop proportions in the animal feeding, but only the intensity at which water is used to grow the crops that feed the animals. The computation is simpler because the green and the blue component of the WI correspond to the ET_{blue} and ET_{green} which are expressed in m^3/ha. The grey fraction is computed in the same way as described in section 2.2.1 without dividing it by crop yield.

2.3. The Database

2.3.1 *Data structure*

Data necessary to compute the WF were collected in collaboration with the case study conductors within the framework of the Strength2Food project. The data can be divided in three groups according to their use in WF computation: meteorological data, cultural data, input data. Table 1 summarizes the three groups and provide details upon their use in WF computation.

Table 1. Data collected for WF and WI computation. Parameters and their units (double slash symbol // indicates a dimensionless parameter) are given. Meteorological and Cultural data are input to CROPWAT and were used to compute the green and blue WF and WI. Input data were used in the LCA approach to obtain an additional quota of the blue WF and WI (water indirectly consumed by farm activities). Input data concerning nitrogen content of fertilizers yielded the grey WF and WI according to the WFN recommendations.

Meteorological Data		**Cultural data**		**Input data**		
Parameter	***Unit***	***Parameter***	***Unit***	***Parameter***	***Unit***	***WF and method***
Monthly Min Temp	°C	Yield	Ton ha^{-1}	Nitrogen in fertilizers	Kg ha^{-1}	Grey, WFN Blue, LCA
Monthly Max Temp	°C	Kc	//	Phosphorus in fertilizers	Kg ha^{-1}	Blue, LCA
Humidity	%	Length of crop stage	days	Pesticides and herbicides	Kg of active principle ha^{-1}	Blue, LCA
Wind	m/sec	Rooting depth	m	Energy (diesel)	Kg ha^{-1}	Blue, LCA
Sunshine	hours	Critical depletion	//	Energy (electricity)	kWh	Blue, LCA
Radiation	$Mj/m^2/day$	Yield response	//	Energy (natural gas)	MJ	Blue, LCA
		Crop height	m	Irrigation water	m^3 ha^{-1}	Blue, LCA
		Planting data	time	Dilution water	m^3 ha^{-1}	Blue, LCA
Green, Blue WF, WFN and CROPWAT				Operational water (e.g. cleaning and washing)	m^3	Blue, LCA
				Grey WF, WFN; Blue WF, LCA, Ecoinvent 3.1		

The duration of the developmental stages of the plants was determined by, considering the growing season as divided in initial, development, mid-season and late season periods. Initial stage runs from planting date to approximately 10% ground cover. The development stage runs from 10% ground cover to effective full cover. Effective full cover for many crops occurs at the initiation of flowering. The mid-season stage runs from effective full cover to the start of maturity. The late season stage runs from the start of maturity to harvest or full senescence. This information was collected for each product and its REF counterpart by case study conductors in the framework of the Strength2food project.

Other essential parameters include the critical depletion fraction and the yield response factor. The former is the critical soil moisture level where first drought stress occurs, affecting crop evapotranspiration and crop production. The latter relates yield decrease to evapotranspiration deficit. In practice, this index describes over the total growing period, how yield would decrease in relation to water deficit. Water deficits in crops, and the resulting water stress on the plant, have an effect on crop evapotranspiration, which is a key parameter for computing WF and WI. To obtain these coefficients for all the crops in this investigation we necessarily exploited the databank provided by the FAO (Allen et al. 1998; Doorenbos and Kassam 1979) because determining their values from field data was beyond the means and scope of Strength2food project.

2.3.2 *Approximations*

We collected meteorological data from all the 23 production regions. For several products no meteorological were available for technical or logistic difficulties. In these cases we exploited CLIMWAT 2.0 a climatic database coupled with CROPWAT. It is a joint publication of the Water Development and Management Unit and the Climate Change and Bioenergy Unit of FAO (http://www.fao.org/land-water/databases-and-software/climwat-for-cropwat/en/).CLIMWAT offers observed agro-climatic data of over 5000 stations worldwide. The DSS derives climatic parameters (see Allen et al. 1988 for details).

Computing the grey WF and WI required several approximations. Primary data to be used are e the amount of fertilizers (nitrogen based and phosphorus based) and that pesticides used in the various crop productions. However, the grey WF and WI were computed on nitrogen only. We excluded pesticides because of the great heterogeneity of the data: in some case we had information on the active principle; in others the information concerned the amount of the substance containing the active principle. Also, problems emerged in finding the maximum allowable concentration for either chemical compounds or active principles although we exploited the EC directive 2008/105/EC (EC 2008). In addition, in some cases the amount applied were not available from case study conductors. However, pesticides were not completely discarded form the analysis; in fact through the LCA approach we had the opportunity to quantify the impact on water resources as blue water that is used to produce these substances. So pesticides enter the WF calculation as blue fraction. This however only partially compensates for the underestimated grey WF impact due to the exclusion of pesticides.

Phosphorus as well was not included in the computation. Difficulties in this case emerged in searching for the maximum allowable concentration in water bodies because such value vary in relation to the trophic state of the receiving water body (Franke et al. 2013), an information that was impossible to collect from case study conductors. Other recent studies quantified grey WF (Aldaya and Hoekstra 2010; Bulsink et al. 2010; Dabrowski et al. 2009, Gerbens-Leenes et al. 2009; Hoekstra2011; Van Oelet al. 2009) on nitrogen base only and others outlined the approximations required to include phosphorus in the computation (Liu et al. 2012). For nitrogen we explored the literature (Chapagain et al. 2006; Chapman 1996; FAO 2006, 2009; Franke et al. 2013; Heffer 2009;) to define standards to be used in the computation. We assumed that the quantity of the chemical that reaches free flowing water bodies is 10 per cent (α=0,1) of the applied fertilization rate (amount applied in kg/ha/yr, primary data) (Hoekstra and Chapagain, 2008). For the maximum allowable concentration in the free flowing surface water bodies the EU set up a value of 50 mg/l of N-NO_3 (which correspond to 11,3 mg-N/l). Being this value a standard imposed for drinking water we set up a slightly higher reference value and equal to 13 mg/l (measured as N), according to Franke et al. (2013). As for the background concentration data on fresh surface water from the EU monitoring stations indicate that 64.3% were below 10 mg nitrate per litre, while 2% showed concentrations between 40 and 50 mg per litre and in 1.8% the concentration exceeded 50 mg per litre. Considering these data and also indications by Franke et al. (2013) we set up the background concentration for this study equal to $(c_{nat} = 0{,}023\ mg/lt)$ which corresponds to $(c_{nat} = 0{,}1\ mg/lt\ N - NO_3)$.

Finally, for each product, a thorough quality check procedure was implemented to limit the risk of misreporting data. The three key aspects of this procedure were 1) to record all data, their date and source in a shared spreadsheet, 2) to separate the person who collected data from the person who estimated the WFWF, and 3) to come up with a written and consensual interpretation of the results between these actors.

All the spreadsheets including the raw data, their source, and the resulting estimated WFs can be found at https://www2.dijon.inra.fr/cesaer/informations/sustainability-indicators/.

2.4. Statistical Analysis

We computed the green blue and grey WF and WI for the 23 FQS products and their 23 REF counterparts. We contrasted the values obtained for these two groups using the signed rank Wilcoxon test (Wilcoxon 1945, R Core Team 2014). The paired test better reflects the nature of the scientific question that is whether each FQS perform better than its REF counterpart. Although the comparison is between the two groups it was logical to pair each FQS product with its counterpart. The small size of the samples and their non-normal distribution (and that of the sample of the differences), tested using the Shapiro-Wilx test (R Core Team 2014; Shapiro and Wilk 1965) suggested to use the non-parametric test. We performed several comparisons considering the main subdivision in three groups: Organic, (and their conventional counterparts), PDO and PGI products. Also we tested FQS against REF in two larger groups that included all animal products and all vegetal products respectively. The comparison was performed for each specific fraction, green, blue and grey for both indicators WF and WI. We executed all the analyses in the R statistical environment (R Core Team 2014). We designed the analysis according to the R instruction: wilcox.test (x, y, alternative = "less", paired = TRUE). We associated the values of the indicator for the FQS products to vector x and those for their REF counterparts to vector y. By setting “less” as alternative hypothesis we asked the programs to test the alternative hypothesis according to which REF products had a lower WF and a lower WI. Thus significant comparisons were those in which WF and WI of FQS products were significantly lower than REF products.

3. Results

The outcomes of the Wilcoxon test are summarized in Table 1. Considering WF, the only significant difference (at 0,1 level of probability) emerged when we contrasted FQS and REF for their blue WF in in the sole group of Organic products. It is the only case in which FQS showed a lower footprint than REF. In all the other comparisons no significant difference was detected between FQS and REF. When the focus was on the impact per unit surface (WI), several comparisons were significant (see Table 4, WI). Considering the green WI, only for the sample that pooled all the animal produced a significant difference between FQS and REF. FQS performed better than REF for blue WI in all the groups. Considering the grey WI we obtained significant differences in all the groups but that of PDO products..

Table 2. Results of the Wilcoxon tests. Each statistics (V) and its probability value refers to the comparison between a FQS product and its REF counterpart for a given Fraction (green, blue, grey) of the Indicator (WF and WI) within a given set of products (Organic, PDO, PGI, Animal, Vegetal).

Indicator	Fraction	Organic	PDO	PGI	Animal	Vegetal
WF (m^3/kg)	Green	V = 28, p-value=1	V = 10, p-value=0,5	V = 29, p-value=0,94	V = 36, p-value=0,95	V = 61, p-value=0,86
	Blue	V = 5, p-value=0,078	V = 13, p-value=0,71	V = 23, p-value=0,76	V = 24, p-value=0,59	V = 35, p-value=0,25
	Grey	V = 12, p-value=0,66	V = 4, p-value=0,109	V = 25, p-value=0,84	V = 31, p-value=0,85	V = 23, p-value=0,112
WI (m^3/ha)	Green	V = 4, p-value=0,209	V = 4, p-value=0,109	V = 3, p-value=0,14	V = 1, p-value=0,017	V = 20, p-value=0,133
	Blue	V = 0, p-value=0,078	V = 1, p-value=0,031	V = 8, p-value=0,09	V = 2, p-value=0,014	V = 11, p-value=0,002
	Grey	V = 1, p-value=0,015	V = 0, p-value=0,031	V = 16, p-value=0,66	V = 1, p-value=0,017	V = 14, p-value=0,004

Figure 1 shows the distributions of the values for blue, green and grey WI of the FQS and REF within the Organic, PDO and PGI pools.

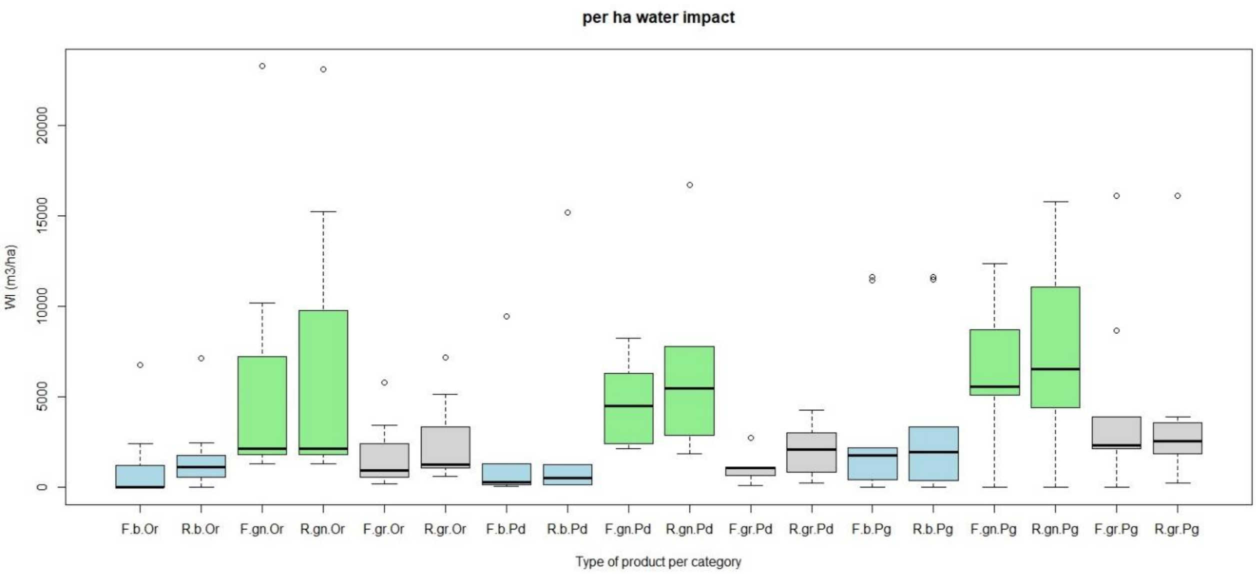

Figure 1. Boxplots representing the distributions of WI values. Colours identify the blue (b), green (gn) and grey (gr) fraction of the indicator. Each couple of adjacent boxplots refers to FQS (F) and REF (R) values within the same group: Organic (Or), PDO (Pd) and PGI (Pg).

Figure 2 shows the box plots for the distributions of the blue, green and grey WI for FQS and REF products within the pooled animal and vegetal groups.

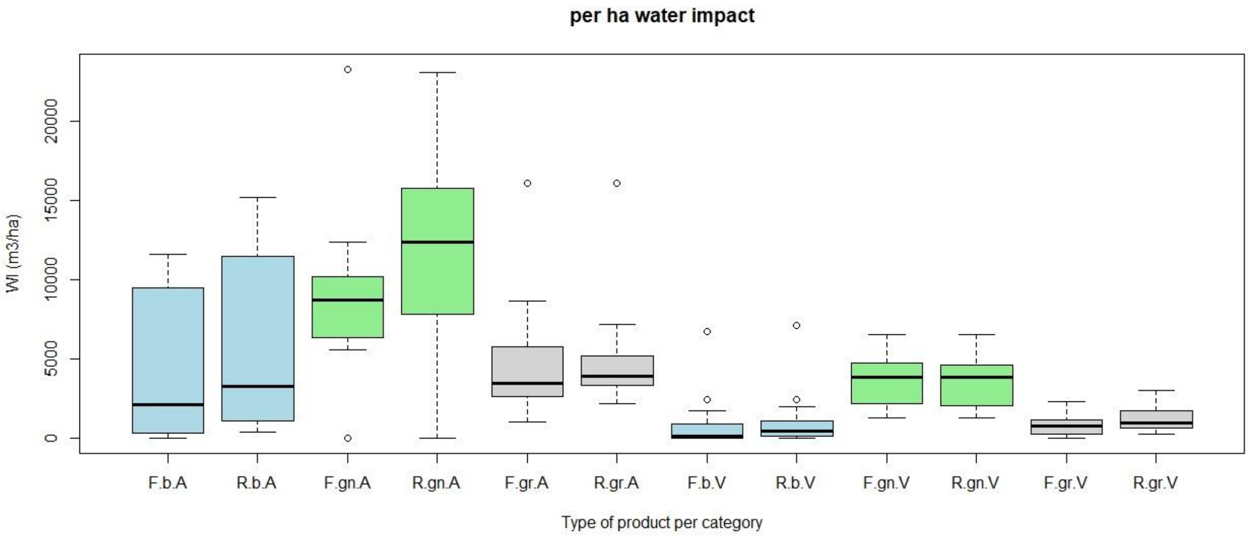

Figure 2. Boxplots representing the distributions of the WI values for FQS and REF as pooled in animal and vegetal products. Colours identify the blue (b), green (gn) and grey (gr) fraction of the indicator. Each pair of adjacent plots refers to FQS (F) and REF (R) products within the animal (A) and vegetal (V) group.

Comparing the values of the green, blue and grey WF, in only 3 cases out of the 23 comparisons the FQS performed better than its REF counterpart for all the three fractions of the indicator (values for every single product are in Table A1 in Appendix). FQS products showed a lower green WF in 5 out of the 23 cases. The ratio increases to 11/23 when the grey WF is considered and to 12/23 in the case of the blue WF. In the group of the Organic products FQS showed a higher green WF in all cases, whereas in 6 out of the 7 products FQS required less of the blue WF than their REF counterparts. In 4 out 7 cases that compose this group FQS showed lower grey WF. In the PDO group (6 cases overall), FQS showed lower green WF then REF in 3 cases; in 2 FQS performed better than REF for the blue WF, and in 4 cases the FQS products showed a lower grey WF. Considering the PGI group (10 cases overall) in 5 cases FQS showed lower grey and blue WF whereas only in 3 comparisons FQS showed lower green WF. Overall, in only 6 cases the FQS showed lower green WF; in 13 cases they showed lower blue WF and 12 out of the 23vFQS showed lower grey WF.
Looking at the per hectare impact (WI values for every single products are in Table A2 in the Appendix) the better performance of the REF products that emerged from the Wilcoxon test has a correspondence in the single product comparisons. In the Organic group in 3 out of 6 cases FQS performs better than REF for all the fraction of the WI. In the other 3 cases, however, the better performance of FQS concerns 2 out of the 3 fractions. The same pattern characterizes the PDO products. In the PGI group only 2 FQS products (out of 10) yielded a lower WI than their REF counterparts for all the three fractions of the indicator. In 2 cases REF performs better than FQS for the three metrics that compose the WI. Overall, in 19 out of 23 cases the FQS required less of the

blue WI. This ratio decreases for the grey WI with FQS showing a lower impact in 17 out of 23 cases. The ratio further decreases considering the green WI, for which FQS performed better then REF in 14 comparisons. The blue WI is always lower for FQS in the group of Organic products; in the PDO group it is the grey WI for which FQS is always better than REF. No pattern of this type characterizes the group of PGI products.

WF of FQS and REF products did not differ significantly. There are cases in which FQS performs better than REF and others in which the opposite occurs, irrespectively from the type of product, be it Organic, PDO or PGI. The large heterogeneity in the results emerges also by considering for each single product the percentage difference in WF values between FQS and REF. There are cases in which this percentage is less than 1%, as for example in the grey WF for the Italian Organic Tomato and its reference counterpart (the former performs worse than the latter) and others in which the values we computed produced a difference between FQS and REF of several orders of magnitude. This is the case, for example, of the grey WF of the Horn Mali Rice (PGI product of Thailand), for which the FQS product requires an amount of water to dilute nitrogen pollution that is by two orders of magnitude lower than its REF counterpart.

Figure 3 shows the share (in percentage) of the consumptive WF by each of the two fractions that compose it.

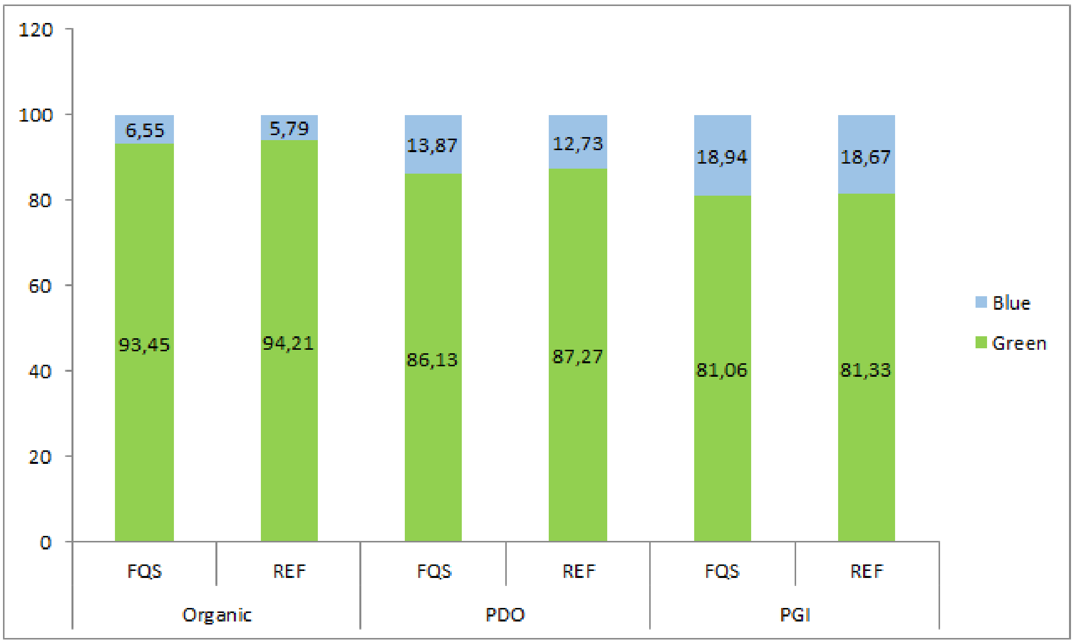

Figure 3. Share (%) of the consumptive WF by the green and the blue fractions for the three groups of products under investigation.

Focusing on this portion of the WF (thus excluding the grey WF) the green fraction has always the greatest share. The blue WF shows the lowest share in the group of Organic products (6%) while it increases above 10% in PDO products (13%) and reaches almost 20% in the PGI group. However, the same computation applied to REF products yielded similar results (Figure 3). Our analysis indicates that the particular way of production (e.g. Organic vs conventional) does not change the balance between green and blue WF. Rather, the specific products sampled are responsible for the difference observed between Organic, PDO and PGI products.

We also tested whether the significant difference between FQS and REF as for the blue WI could be due to a different contribution from the blue LCA WI with respect to WI as irrigation requirement(ET_{blue}). It is important to remember here that by LCA we estimated all the water necessary to sustain the farming activities (see Methods), except for water that satisfies irrigation requirement. Pooling together all the products and contrasted FQS and REF products for the two components of the blue WI, the Wilcoxon test revealed that FQS required significantly less water both for irrigation (per hectare) (V=8, p-value=0.02639) and to sustain farming activities (blue LCA WI, V=34, p-value=0.00244).

4. Discussion

We computed green, blue, and grey WF and WI of FQS Organic, PDO and PGI products and contrasted with the values for their REF counterparts. We also contrasted FQS and REF products in the two larger set in which we pooled animal and vegetal products. The striking evidence of this analysis is that a clear significant difference emerges when the focus is on the impact per unit area (ha). In particular, FQS products showed a significantly lower impact than REF for the blue and grey WI, whereas, with the exception of the pooled animal products, FQS and REF do not show significant difference when the focus is on green WI. As the statistical analysis has shown, the reduced blue WI of FQS products is the outcome of a contemporary lower demand for irrigation and a lower consumption of water to sustain farming practices. The lower water requirement to sustain farming activities is associated to the null or lower use of mineral fertilizers and the null or lower amount of pesticides and herbicides. If this can be somehow expected for organic products (V = 0, p-value = 0.007813), not necessarily so was for PDO products (V = 0, p-value = 0.01563). In fact the Code of Practice for Organic products are in general more restrictive on the use of fertilizers and pesticides. It seems thus that the Code of Practice for PDO imposes constraints to the production process that reflects also on a lower water requirement. This is not the case for PGI products which did not show such pattern given that the differences between FQS and REF were not significant. It is important to highlight here that blue water is expensive to use, since it has a high opportunity cost (Lovarelli et al. 2013). Reducing its use, both production costs (e.g., energy for pumping, machines and plants to buy and manage) and environmental impacts (due to energy, materials, plants, etc.) are reduced as well.

Our results suggest that the farming systems employed in FQS productions may be more environmental friendly: they require less blue water for one hectare of production and less water to dilute the nitrogen applied as fertilizer (grey water). Thus in principle a larger diffusion of these methods of production could reduce the amount of water to be withdrawn from surface waters, and would have a lower pollution impact. Thus FQS productions can in principle be more adequate in situation of water scarcity, a condition that is becoming more and more diffuse because of the climate change, which is likely to exacerbate regional and global water scarcity considerably (Mukheibir 2010; Shewe et al. 2014). WF is obtained dividing WY by the yield (see Methods). In many cases yield for FQS was lower than REF and this turned the significant difference in water consumption per unit surface (in favour of the FQS) into a non-significant difference per unit product. A larger demand of FQS products, given the lower yield in respect to REF, may imply an extension of the area dedicated to these productions with a consequent overall increase of water demand. From a management perspective the focus may be to decrease the field evapotranspiration (ET) over the growing period per unit of yield (Y) (consumptive water footprint, Hoekstra et al., 2011) or to increase the water productivity, that is yield per unit water lost through evapotranspiration (Y/ET, water productivity, Molden et al., 2010). Chukalla et al. (2015) posited that increasing water productivity can be achieved through a combination of irrigation techniques, irrigation strategies and mulching practices. Combined with our results this evidence suggests that the sole farming system (Organic, PDO, PGI) may not be effective in reducing WF but it need to be associated with a general improvement of techniques and strategies for water use, and must be evaluated by carefully considering agro-ecological conditions, water availability constraints and management practices (Amarasinghe and Smakhtin 2014).

The different results we obtained for WF in comparison with WI depend on several factors. For vegetal products yield is the most relevant. Thus, the lower yield that often characterizes non-conventional productions contributes to make their WF per unit product higher than that of conventional productions. Of the 14 vegetal products that compose our sample, in 9 cases the FQS showed lower yield then REF. In all of them at least for 2 out of the three WF fractions the FQS showed higher value than REF. Considering the animal products, the analysis is more complex because animals are fed with a mixed diet involving multiple crops. Thus the different crop yield combines with the different proportion in which each crop enters the diet of FQS and REF animals to affect the value of the indicator. Also, conversion factors (e.g. product concentration and efficiency of transforming feed into food) play a role: the way efficiency characterizes a productive chain acts as a strong constraint to water needs per unit product in both conventional and non-conventional systems. One possibility to reduce pressure on water resources is selecting mixed diets in which crops with lower water demand enter in higher amounts but this must be carefully evaluated according to the nutritional values of crops in relation to animal productivity. Crops that would guarantee a reduced water impact may also lower efficiency of transforming feed into food, and overall the WF may not diminish.

The scenario depicted in Figure 3 highlights that vegetal products and the crops used to feed the animals satisfy most of their water requirements through the rainfall and rely on irrigation for a rather small fraction of their needs. Under the effect of climate change an increasing temperature coupled with decreasing precipitations (Bocchiola et al. 2013) may increase plant evapotranspiration, with less rainfall to compensate for it. This would imply an increased demand of blue water (WF and WI), with a consequent increase of water withdrawal. Alternative farming system (Organic, PDO and PGI) do not show a different share of the WF in respect to REF (Figure 3). It follows that consequences of climate change may be the same irrespectively of the farming system adopted. Possibilities to mitigate water scarcity lie in the design of efficient irrigation strategies and technologies; also a deeper analysis of crop performances should be conducted under specific conditions and using multiple indicators such as water productivity, water-use efficiency, irrigation-efficiency and the index of water scarcity (Barker et al. 2003; Damkjaer and Taylor 2017). One possibility is to consider virtual water trade to compensate for water shortages (Wichels 2001, Huang et al. 2019). However it is difficult to imagine this as a reliable solution when non-conventional farming systems are rigidly controlled by their Code of Practice as in the case of many Organic, PDO and PGI products.

The result we obtained contrasting FQS and REF for their WI and WF are statistically based. This offers an overview of the impact that the considered farming systems have on the water resources going beyond the usual analysis based on WF computation (Lovarelli et al. 2016 Mekonnen and Hoeckstra 2011, 2014). This overview may become more accurate by extending the sample of products, but this requires a great effort in collecting reliable data: from meteorological to cultural data and input data for LCA applications. The non-significant result obtained in most of the WF comparisons WF comes from single cases in which REF are less impacting than FQS, and others in which the performances of the two contrasted products are similar. In no cases, however, the statistics told us that REF products impact less on water than FQS.

When yield enters the computation, as we pass from WI to WF, the better performance of FQS vanishes. The focus on water consumption per unit surface is however important at a local scale because it is the water that is available in the production area which imposes constraints to productivity, and planning the use and the distribution of the resource by local authorities is of primary importance. In this perspective, according to our results, FQS products may offer more opportunity than conventional products for a better distribution/preservation of the resource. However if environmental impact must enter in the criteria to select products by the consumers, then what is interesting is the WF, that is the impact per unit product. From this point of view our results indicate that alternative farming schemes are not yet able to make a difference in respect to conventional productions.

5. Conclusions

This work constitutes a first attempt to make an extensive analysis of how non-conventional or certified productions impact water resources in comparison with conventional systems. The results we obtained highlight that the potential benefit associated with non-conventional production is visible mostly when the focus is on WI, that is water consumption per unit area. The analysis of the results also suggests that this difference is mostly due to LCA blue WI and the grey WI, the two fractions that largely depend on the use of fertilizers and pesticides, which are applied in lower quantities in non-conventional productions.
When the focus is on WF, that is water required per unit of final products, non-conventional, certified productions do not perform any better statistically than their conventional reference products. This depends on the yield of the cultivars but also on the different efficiencies to obtain the final product. We present this result with circumspection; in fact for the reasons described above (see Methods: Approximations) we did not take into account several factors that might have increased the impact of conventional products, especially in terms or their grey water requirement.
Studies like the one presented here are not easy to perform accurately. The amount of information that is needed implies a great effort in collecting data and often they must be gathered from national or other databases, which make the final result a rough estimate of the real impact of the production systems. We believe however that increasing the accuracy of the estimation is possible and this may help improving the use of WF to ascertain the advantage of FQS also in terms of environmental impact and, in particular, on water resources.

6. References

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7. Appendix

List of the Food Quality Schemes and their Reference counterparts within Organic, PDO, PGI.

ORGANIC

Case studied (FQS)	Country	Reference product (REF)
Organic flour	France	National average
Camargue rice	France	Non-organic rice (mostly PGI)

Organic pork	Germany	National average
Organic yoghurt	Germany	National average
Organic tomato from Emilia Romagna Region	Italy	Conventional processed tomatoes in the same region (Emilia-Romagna)
Organic pasta	Poland	Simulated conventional farms with sample characteristics
Organic raspberries	Serbia	National average

PDO

Case studied	Country	Reference product
PDO olive oil	Croatia	National average
Comte cheese	France	National average (cow cheese)
Zagora apple	Greece	Kissavos apples (non-GI apples from another region)
Kalocsai paprika powder	Hungary	Imported Chinese pepper milled in Hungary
Parmigiano Reggiano cheese	Italy	Biraghi cheese (similar non-PDO cheese)
Opperdoezer Ronde potato	Netherlands	Regular potato in neighbouring IJsselmeerpolders region

PGI

Case studied	Country	Reference product
Dalmatian ham	Croatia	Local non-PGI firm
Kastoria apple	Greece	Kissavos apples (non-GI apples from another region)
Gyulai sausage	Hungary	Non-PGI Hungarian sausage
Kaszubska strawberries	Poland	National average
Sjenica cheese	Serbia	National average (cow cheese)
Sobrasada of Mallorca	Spain	National average
Ternasco de Aragon	Spain	Non-PGI lamb in the same region (Aragon)
Thung Kula Rong-Hai (TKR) Hom Mali rice	Thailand	Non certified rice from the same region (90% of GI rice is organic as well)
Doi Chaang coffee	Thailand	Non-PGI coffee from the same province
Buon Ma Thuot coffee	Vietnam	Non-PGI coffee from Dak-Lak province in Vietnam

WI	**Organic**				**PDO**				**PGI**
	Org. Rice	**REF**		**Olive oil**	**REF**		**Buon Ma Tout**		**REF**
WI green	1300	1300	0	2872.24	2873.7	1.46	6546	6546	0
WI blue	6762.81	7128.95	366.14	139.81	146.77	6.96	1758.94	1984.55	225.61
WI grey	393.67	1181.01	787.34	689.08	837	147.92	2321.8	2582.32	260.52
	Org. Pasta	**REF**		**Kalocsai**	**REF**		**Doi Chaang**		**REF**
WI green	1685.99	1688.61	2.62	2441	4837.5	2396.5	4417	4417	0
WI blue	2.69	10.48	7.79	1296.95	1290.83	-6.12	566.91	433.575	-133.335

WI grey	186.01	604.23	418.22	1130.62	3015	1884.38	2312.810015	1869.9315	-442.87851
	Org. Pork	**REF**		**Parmigiano**	**REF**		**Horn Mali**		**REF**
WI green	10194.986	15263.275	5068.289	6330.07	7819.45	1489.38	5388.2031	5390.6622	2.4591
WI blue	15.244	1118.581	1103.337	9464.02	15186.85	5722.83	0.1967	3.7884	3.5917
WI grey	3448.532	5169.779	1721.247	997.67	2245.1	1247.43	34.4225	253.9614	219.5389
	Org. Yoghurt	**REF**		**Comté**	**REF**		**Kastoria**		**REF**
WI green	23294.37	23107.91	-186.46	8261.43	16739.43	8478	5108.01	3405.01	-1703
WI blue	44.19	1117.16	1072.97	342.22	523.58	181.36	81.96	129.22	47.26
WI grey	5788.86	7200.42	1411.56	2750.88	4284.49	1533.61	153.25	275.56	122.31
	Org. Tomato	**REF**		**Opperdoezer**	**REF**		**Dalmatian**		**REF**
WI green	1963	1963	0	2156	1855.5	-300.5	9957.87	11068.36	1110.49
WI blue	2410.77	2466.46	55.69	297.5	496.61	199.11	437.1	410.95	-26.15
WI grey	1377.84	1574.68	196.84	1141.64	1965.55	823.91	2656.12	2174.29	-481.83
	Org. Flour	**REF**		**Zagora**	**REF**		**Gyulai**		**REF**
WI green	2146.97	2162	15.03	6166	6165.99	-0.01	2.08	2.08	0
WI blue	38.65	275.14	236.49	77.9	152.71	74.81	11479.31	11481.39	2.08
WI grey	781.87	1266.04	484.17	91.33	275.56	184.23	16123.51	16123.51	0
	Org. Raspberries	**REF**					**Proc Negre**		**REF**
WI green	4314.87	4314.9	0.03				5598.729	7427.645	1828.916
WI blue	13.66	842.46	828.8				2191.965	3247.815	1055.85
WI grey	960.66	960.45	-0.21				8676.434	3580.555	-5095.879
							Ternasco		**REF**
WI green							12378.67	12378.67	0
WI blue							11622.54	11622.54	0
WI grey							3908.27	3908.27	0
							Sjenica		**REF**
WI green							8711.28	15807.98	7096.7
WI blue							2130.04	3376.37	1246.33
WI grey							2130.04	3354.8	1224.76
							Kaszubska		**REF**
WI green							3825	3852	27
WI blue							261.54	353.97	92.43
WI grey							639.32	651.92	12.6

Table A1. Values for green, blue and grey WI for the 23 selected FQs products and their REF counterparts.

WF	**Organic**			**PDO**			**PGI**		
			Diff. REF-FQS			Diff. REF-FQS			Diff. REF-FQS
	Org. Rice	**REF**		**Olive oil**	**REF**		**Buon Ma Tout**	**REF**	
WF green	0.48	0.39	-0.09	8.92	19.64	10.72	3.40	3.38	-0.02
WF blue	2.50	2.12	-0.38	0.43	1.00	0.57	0.96	1.10	0.14
WF grey	0.15	0.35	0.21	2.14	5.72	3.58	1.21	1.33	0.12
	Org. Pasta	**REF**		**Kalocsai**	**REF**		**Doi Chaang**	**REF**	

WF green	1.58	0.76	-0.82	0.93	1.51	0.58	18.04	13.80	-4.24
WF blue	0.00	0.00	0.00	0.50	0.40	-0.10	2.32	1.35	-0.96
WF grey	0.17	0.27	0.10	0.43	0.94	0.51	9.45	5.84	-3.60
	Org. Pork	**REF**		**Parmigiano**	**REF**		**Horn Mali**	**REF**	
WF green	19.56	11.25	-8.31	4.33	2.98	-1.35	4.26	5.56	1.30
WF blue	0.07	0.69	0.62	7.34	5.84	-1.50	0.00	0.01	0.00
WF grey	6.22	2.86	-3.36	0.51	0.77	0.26	0.01	0.26	0.26
	Org. Yoghurt	**REF**		**Comté cheese**	**REF**		**Kastoria**	REF	
WF green	1.00	0.62	-0.38	6.97	7.23	0.26	1.19	0.97	-0.22
WF blue	0.01	0.03	0.01	0.27	0.32	0.06	0.02	0.04	0.02
WF grey	0.11	0.12	0.00	1.32	1.29	-0.03	0.04	0.08	0.04
	Org. Tomato	**REF**		**Opperdoezer**	**REF**		**Dalmatian**	REF	
WF green	0.06	0.05	-0.01	0.09	0.04	-0.05	74.23	68.57	-5.67
WF blue	2.57	6.72	4.15	0.01	0.01	0.00	2.89	2.74	-0.16
WF grey	0.04	0.04	0.00	0.05	0.04	-0.01	14.43	12.97	-1.46
	Org. Flour	**REF**		**Zagora**	**REF**		**Gyulai**	**REF**	
WF green	0.63	0.34	-0.30	4.57	1.76	-2.81	55.21	48.75	-6.47
WF blue	0.01	0.04	0.03	0.06	0.04	-0.01	1.48	1.31	-0.17
WF grey	0.23	0.20	-0.03	0.07	0.08	0.01	7.35	6.49	-0.86
	Org. Raspberries	**REF**					**Proc Negre**	**REF**	
WF green	1.60	0.76	-0.84				4.17	5.43	1.26
WF blue	0.02	0.15	0.13				1.61	2.65	1.04
WF grey	0.36	0.17	-0.19				1.78	2.82	1.04
							Ternasco		
WF green							47.51	41.57	-5.94
WF blue							32.04	28.04	-4.00
WF grey							11.75	10.28	-1.47
							Sjenica	REF	
WF green							2.01	4.25	2.24
WF blue							0.03	0.21	0.18
WF grey							0.12	0.55	0.43
							Kaszubska		
WF green							0.43	0.35	-0.08
WF blue							0.03	0.03	0.00
WF grey							0.07	0.06	-0.01

Table A2. Values for green, blue and grey WF for the 23 selected FQs products and their REF counterparts.