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An assessment of India's virtual water trade in major food products

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Abstract This paper analyzes virtual water trade flows through food products between India and its trading partners. It relies on the gravity model of trade and estimates a panel data fixed effect regression to identify drivers of virtual water trade. Our results show that India was the net exporter of virtual water in food products during 1990-2013; however later it turned out to be its net importer. Further our analysis shows distance between trading partners as the primary driver of virtual water trade. India prefers trading with its neighbours to reduce transportation costs. The availability of arable land and water used in crop production are limiting factors for production of food crops and thus act as essential factors in deciding the virtual water trade flows. These findings indicate that resource endowment factors influence bilateral virtual water trade flows.

Keywords Fixed effects regression, Food crops, Gravity model, Virtual water trade

JEL Codes F14, Q17, Q25

Production agriculture requires water, and the water embedded in the final product is called virtual water (Allan, 1993). The same concept is referred to as 'embedded water' (Allan, 2003) and 'water footprint' (Mekonnen and Hoekstra 2011). Mekonnen and Hoekstra (2011, 2011a, 2012) provide a detailed country-wise water footprints of crops, derived crop products, biofuels, livestock products, and industrial products.

When the final output with embedded water is traded in domestic and international markets, it is termed as a Virtual Water Trade (VWT). The quantity of global VWT during 1995-1999 was computed by Hoekstra and Hung (2002, 2005) for crops, and by Chapagain and Hoekstra (2003) for livestock and livestock products. Mekonnen and Hoekstra (2012a) assessed the global VWT for crops, livestock, and industrial products during 1996 - 2005.

Applying the idea of VWT in the context of water-saving, the import of water-intensive products leads to saving of water. It lessens the burden on the country's scarce water resources. However, it is necessary to exchange agricultural products to ensure nation's food security. Hence, there is always a trade-off between food security and water-saving through trade. Agriculture is one of the sectors which intensively uses water. With highly uneven rainfall and frequent departures from normality, water scarcity has become a significant concern in India which is expected to be exacerbated by climate change. It will affect the livelihoods of millions of farmers (Rodell et al. 2018). The situation is further aggravated as the marginal and small landholdings dominate Indian agriculture with inadequate adaptive capacity. Hence, improving water use efficiency along with developing efficient water management practices are important.

The concept of virtual water trade is crucial to understand water management strategies to utilize available water resources through trading agricultural commodities. In the agriculture sector, the extent of virtual water trade varies widely across countries and food products. Such differences in the quantity of virtual water trade arise due to various factors. Hence, examining the drivers of virtual water trade will help formulate well-informed regulations on export and import of food products. With this background, this paper focuses on estimating virtual water trade and its determinants.

Materials and methods

Estimation of India's net virtual water trade for crops

Crop-specific virtual water content (VWC) is the basis for estimating the extent of net virtual water trade in food products between India and its trading partners. We relied on virtual water content estimates given by Mekonnen and Hoekstra (2010). We followed the computation method given by Yang et al. (2006) to assess the extent of virtual water export and import. In 2017, India exported 52 crop products and imported 50 crop products (Appendix 1). All these products were considered to assess the magnitude of the virtual water trade. The time series data (1990-2017) on quantities of food products exported and imported by India was extracted from the FAOSTAT.

The gross volume of virtual water export (GVWE) from India is estimates as

$$GVWE_{tij} = \Sigma\ (Crop\ Product\ Exports_{pt} * VWC_{pi})$$

The gross volume of virtual water import (GVWI) to India is estimated as

$$GVWI_{tij} = \Sigma\ (Crop\ Product\ Imports_{pt} * VWC_{pi})$$

Where i is an exporting country, j is an importing country, p is a crop product, t is time, and VWC is virtual water content.

Net virtual water trade (NVWT) is given by

$$NVWT_{tij} = GVWI_{tij} - GVWE_{tij}$$

The gravity model of trade: variables, data, and empirical specification

The gravity model explains trade flows between trading partners, and resembles the universal law of gravitation (Bergstrand 1985).

$$F_{ij} = \beta_0 \frac{v_i v_j}{d^2_{ij}}$$

Where, F_{ij} is the trade between countries i and j. v_i and v_j are values of the relevant variable for the country i and j, and d is the distance between the countries. A general specification of the gravity model of trade used by Head and Mayer (2014) includes a broader variety of determinants of bilateral trade, and can be written as

$$X_{ij} = GS_i{}^{\alpha} S_j{}^{\beta} Y_{ij}{}^{\gamma}$$

$$X_{ij} = GS_i^{\alpha} S_j^{\beta} Y_{ij}^{\gamma}$$

The gravity model of trade is a model of bilateral trade interactions in which size and distance effects enter multiplicatively, where S_i represents all the features that affect the exporter i as all partners, S_j captures all features of j as a destination market from all sources, and Y_{ij} is a measure of the accessibility of market j for the producers of country i, and it subsumes any other pair-specific factor influencing bilateral trade. The multiplicative expression of the gravity equation can be estimated more easily employing Ordinary Least Square (OLS) estimators after taking logs of the equation.

Above mentioned classical gravity model generally uses one time period data to estimate determinants of trade. However, the time trend in panel data captures the time fixed effects. Tamea et al. (2014) used 25 years of cross-sectional data to study the determinants of virtual water trade. The advantages of panel data are two-fold. It captures the relevant relationships among variables over time and looks for unobservable trading partner pairs' individual effects. Therefore, we used panel data for estimating the gravity model of the virtual water trade.

Given the multiple partner countries involved in a trading relationship, the panel data takes into account export or import of specific commodities with various countries over time. For the model describing virtual water import and virtual water export, we rely on the modified form of the model used by Tamea et al. (2014). Here, we look for two gravity laws for India: one describing the export as a function of the characteristics of destination countries, and another describing the import as a function of the characteristics of source countries.

Identifying the exporting country by *i* and the importing country by *j*, two different estimates are given for the virtual water trade from country *i* to country *j* as follows:

$$VWE_{ij} = \beta_0 \, (gdppc_j)^{\beta 1j} \, (pop_j)^{\beta 2j} \, (D_{ji})^{\beta 3j} \, (pcl_j)^{\beta 4j} \, (vwp_j)^{\beta 5j}, \; j \in \Omega_d \, (i) \quad \ldots(1)$$

$$VWI_{ij} = \text{b0} \, (gdppc_i)^{b1i} \, (pop_i)^{b2j} \, (D_{ji})^{b3i} \, (pcl_i)^{b4i} \, (vwp_i)^{b5i}, \; i \in \Omega_d \, (j) \quad \ldots(2)$$

Where, *VWE* is a virtual water export, *VWI* is a virtual water import, *gdppc* is the gross domestic product per capita, *pop* is population, *D* is the distance between India and the trading partner, *pcl* is per capita availability of arable land, and *vwp* is virtual water used in the production of corresponding crops.

Equation (1) expresses the demand's pull for export, describing the virtual water export as a function of destination characteristics, referred to as the export law. Similarly, Eq.(2) expresses the supply's push for import, describing the virtual water import as a function of source characteristics, referred to as the import law (Tamea et al. 2014).

The dependent variable is the total amount of water embodied in the food products exchanged between India and partner countries (i.e, virtual water export / virtual water import). To obtain the VWE and VWI estimates of country-specific virtual water content (CVWC) for various crop products provided by Mekonnen and Hoekstra (2010) are multiplied by the quantity of exchanged food products registered in the international trade data from the FAOSTAT database.

$$VWE_{pijt} = Export\ quantity_{pijt} * CVWC_{pi}$$

$$VWI_{pijt} = Import\ quantity_{pijt} * CVWC_{pj}$$

Among the independent variables of the virtual water trade, the foremost to be used are variables measuring the economic mass of the countries, i.e., population (pop), GDP per capita (gdppc) and the geographical distance (D) i.e., the average physical distance between the most populated cities of any pair of countries given by CEPII (*http://www.cepii.fr/anglaisgraph/bdd/distances.htm*), as in Tamea et al. (2014).

The resources used in agricultural production are other potential factors driving virtual water trade. The measure of the availability of land for cultivation, i.e., per capita availability of arable land (pcl) and virtual water used in crop production (vwp) are other determinants of export or import of agricultural products. The time series data (1990-2017) on availability of arable land and water in India's trade partner countries were extracted from the FAOSTAT.

Virtual water used for crop production (VWP_c) is calculated by multiplying country-specific virtual water content (CVWC) of crops (Mekonnen and Hoekstra, 2010) with the quantity of crop production:

$$VWP_{cit} = Production_{cit} * CVWC_{ci}$$

$$VWP_{cjt} = Production_{cjt} * CVWC_{cj}$$

Both dependent and independent variables are converted into logarithm of base 10. So, identifying the exporting country by *i*, importing country by *j*, for crop products *p*, crops *c*, for time *t*, the following model is proposed for gravity model.

The gravity model of export is:

$$ln\ (VWE_{ijpt}) = \beta_0 + \beta_{1j} ln(gdppc_{jt}) + \beta_{2j} ln(pop_{jt}) + \beta_{3j} ln\ (D_{ij}) + \beta_{4j} ln(pcl_{jt}) + \beta_{5j} ln(vwp_{cjt}) + e_{ijct} \quad \ldots(3)$$

The gravity model of import is:

$$ln\ (VWI_{ijpt}) = \beta_0 + \beta_{1i} ln(gdppc_{it}) + \beta_{2i} ln(pop_{it}) + \beta_{3i} ln\ (D_{ij}) + \beta_{4i} ln(pcl_{it}) + \beta_{5i} ln(vwp_{cit}) + e_{ijct} \quad \ldots(4)$$

Method of estimation of the gravity model

Gravity model involving panel data intended to examine heterogeneity or individual effect that may or may not be observed. If the heterogeneity effect does not exist in data, ordinary least squares (OLS) produce efficient and consistent parameter estimates. However, as Head and Mayer (2014) pointed out the pooled OLS for panel data estimates may no longer be the best unbiased linear estimator due to individual effect not being zero in panel data. This heterogeneity leads to disturbances that vary across individuals (heteroskedastic) and/or are related to each other (autocorrelation).

To examine the heterogeneity effect, the fixed effect panel data model is valid. A fixed effect model examines group differences in intercepts. The "within" estimation method of fixed effect panel data regression does not need to create dummy variables. It thus has large degrees of freedom, smaller Mean Squared Error (MSE) and smaller standard errors of parameters than those of the least squares dummy variable (LSDV) method. Also, Fracasso (2014) argues that the fixed effect model sufficiently captures the heterogeneity effect, thereby warning against pooling (pooled OLS) all the entities. Also, Fracasso argued that adopting gravity equations for panel data, as done by Tamea et al. (2014), is a more appropriate approach. In addition, robust standard errors are used to obtain unbiased standard errors of coefficients under heteroscedasticity.

After incorporating time fixed effect in the model, the gravity model of export is:

$$ln\ (VWE_{ijpt}) = \beta_0 + \beta_{1j} ln(gdppc_{jt}) + \beta_{2j} ln(pop_{jt}) + \beta_{3j} ln\ (D_{ij}) + \beta_{4j} ln(pcl_{jt}) + \beta_{5j} ln(vwp_{cjt}) + \rho_j + e_{ijct} \quad \ldots(5)$$

And, the gravity model of import is:

$$ln\ (VWI_{ijpt}) = \beta_0 + \beta_{1i} ln(gdppc_{it}) + \beta_{2i} ln(pop_{it}) + \beta_{3i} ln\ (D_{ij}) + \beta_{4i} ln(pcl_{it}) + \beta_{5i} ln(vwp_{cit}) + \rho_i + e_{ijct} \quad \ldots(6)$$

where, ρ_j and ρ_i are the time fixed effect coefficients for importing countries and exporting countries, respectively.

We prepared a panel dataset for the top 3 commodities (crop products) of exports and imports in terms of virtual water content to conduct the empirical analysis. The time fixed effect within the estimation regression method was applied for each commodity separately. Crop products selected for virtual water export (Table 1) are milled rice, refined sugar and groundnut shelled. These commodities contributed 68% of virtual water export from India in crops During the Triennium ending (TE) 2017. Similarly, commodities selected for virtual water import (Table 1) are palm oil, soybean oil and sunflower oil. These commodities contributed 61% of virtual water import in crops during TE 2017. All data are annual values for the years 1991 to 2017. The countries included in the estimation were chosen based on data availability so that there is no missing data for any variables. The exact number of countries and the total number of sample used for analysis is given in Table 2.

Results and discussion

Net volume of the virtual water trade

Quantity of net virtual water trade (NVWT) in food crops shows that until 1998 India was the net exporter of virtual water in food products (Figure 1). However, during 1999-2013, we see a mix of net export and net import of virtual water in food crops. During 1999-2001, 2006, and 2009 India was the net importer of water in food crops. These results are in line with the findings of Hoekstra and Hung (2002) that during 1995-1999 India was a net exporter of virtual water. However, after 2013, India became the net importer of water in food crops. India's changing position from a net exporter to a net importer of virtual water from

Table 1 Crop products considered for virtual water export / import and corresponding crops considered for virtual water production

Virtual water export		Virtual water import	
Crops for VWP	Crop product for VWE	Crops for VWP	Crop product for VWI
Paddy	Milled rice	Soybean seed	Soybean oil
Groundnut	Groundnut shelled	Sunflower seed	Sunflower oil
Sugarcane	Refined sugar	Palm kernel	Palm oil

Note CVWC for crops and crop products are different

Table 2 Sample size and number of countries considered for analysis

Virtual water export			Virtual water import		
Crop product	No. of countries	Sample size	Crop product	No. of countries	Sample size
Milled Rice	98	1739	Soybean oil	22	189
Groundnut shelled	45	594	Sunflower oil	19	142
Refined sugar	43	560	Palm oil	9	94

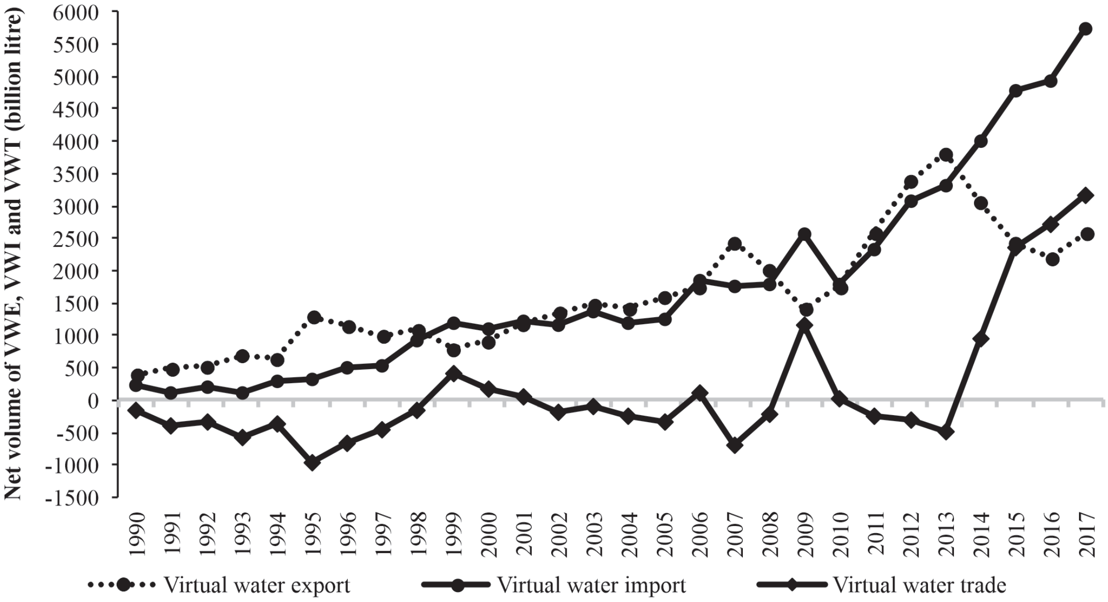

Figure 1 Net volume of virtual water trade of India

2014 to 2017 is due to changes in the composition of quantity exported and imported. There was a decline in the export of milled rice, soybean cake and wheat flour, which are water-intensive products. At the same time, there was a significant spike in the import of oil products especially, sunflower oil, soybean oil and oil palm.

Several studies have highlighted the role of global virtual water trade in water-saving and food security (Hoekstra and Hung 2002, Chapagain and Hoekstra 2003, De Fraiture et al. 2004, Mekonnen and Hoekstra 2012a). The water productivity differences between trading countries generate water savings (De Fraiture et al. 2004). Hence, the water deficit countries can gain through importing virtual water from water-surplus countries instead of producing water-intensive commodities locally. Oki and Kanae (2004) estimated that the global water saving from the virtual water trade was about 455 Giga cubic meters (Gm^3) per annum. Muratoglu (2020) showed that between 2008 and 2019, Turkey's annual water-saving through the virtual water trade was 7.8 Gm^3. The global virtual water deficit due to the wheat trade is 1.76 Gm^3/year. Alamri and Reed (2019) concluded that during 2000-2016, the virtual water trade reduced Saudi Arabia's water deficit by 54%. However, virtual water trade may also lead to water wastage when lower water productive countries export more virtual water to high water productive countries.

Drivers of virtual water export from India

A gravity model for the virtual water export of milled rice includes all the five variables that typically enter the model (Table 3). Both economic mass related variables viz per capita GDP and population of importing countries are found to have a significant positive association with virtual water export of milled rice from India. On the other hand, the average per capita availability of arable land in the importing country is negatively and significantly associated with the virtual water export of milled rice from India. Similarly, there is a significant inverse relationship between the volume of virtual water used in paddy production in importing countries and the virtual water export of milled rice. The distance between India and its trading partners is also a significant factor influencing the virtual water export. India tends to export more to its immediate neighbouring countries.

The virtual water export of refined sugar from India is positively related to importers' population. Therefore, it implies that India tends to export a higher quantity of refined sugar to populated economies. However, among other variables entered into the gravity model, per capita availability of arable land, the quantity of virtual water used in sugarcane production and distance between India and importing countries were found to have a significant negative influence on India's export of refined sugar.

Table 3 Drivers of virtual water export from India

Variables	Milled rice	Refined sugar	Groundnut Shelled
lngdppc	0.132**	-0.031	-0.308
	(0.053)	(0.048)	(0.264)
lnpop	0.512***	0.444***	0.642***
	(0.058)	(0.056)	(0.068)
lnpcl	-0.130**	-0.245*	-0.678***
	(0.053)	(0.137)	(0.065)
lnvwp	-0.068*	-0.242***	-0.102***
	(0.037)	(0.072)	(0.032)
lndist	-0.478***	-1.375***	-0.268***
	(0.109)	(0.164)	(0.086)
Constant	15.66***	22.56***	12.14***
	(0.987)	(1.399)	(1.989)
Observations	1,739	566	594
No. of years	28	28	28
F-stat	64.79***	49.33***	33.18***
R-squared	0.552	0.526	0.663

Note Robust standard errors in parentheses, Level of significance *** p<0.01, ** p<0.05, *p<0.1

Virtual water export of groundnut is more prominent when the trading countries are populated. On the other hand, India's virtual water export of groundnut shelled significantly decreases with a higher per capita availability of arable land in importing countries. Furthermore, the distance between India and importing partners is significant and negative, indicating that countries nearer to India import more groundnut shelled than distant countries.

Overall, the distance between India and importing countries, which is a proxy for transportation cost, is the primary driver for the virtual water export of the commodities under study. Virtual water used in agricultural production negatively influences virtual water export of selected food products. Whereas, per capita availability of arable land is negatively related to the virtual water export of all except wheat flour. Virtual water export is positively related to the population of importing countries for milled rice, refined sugar, and groundnut shelled. Per capita GDP is positively influencing the virtual water export of only milled rice and soybean cake. A similar study conducted by Kumar and Singh (2005) showed that the quantity of available land is one factor that limits the production of agricultural goods and thus virtual water exports.

Drivers of virtual water import to India

The gravity model for India's virtual water import of soybean oil, sunflower oil and palm oil showed that the per capita GDP is a significant driver of the import law (Table 4). The population of exporting countries had no significant influence on India's virtual water import. When source countries are considered under import law, an import flux is higher from the partner countries with more arable land. So, the per capita availability of arable land positively and significantly influences virtual water import in the case of soybean oil and sunflower oil, except palm oil. Virtual water used in producing these crops in exporting countries has a favourable influence on India's virtual water import, as higher production in source countries led to more products available for export. This effect was high in the case of palm oil. It is noted that Indonesia, Malaysia, the Philippines and Thailand are the four major palm oil-exporting countries to India. Among these, India imports more than 95% of palm oil from Indonesia and Malaysia. Both these significant oil palm producers are located in south-east Asia, reducing the

Table 4 Drivers of virtual water import to India

Variables	Soybean oil	Sunflower oil	Palm oil
lngdppc	2.028***	1.715**	0.593**
	(0.326)	(0.651)	(0.219)
lnpop	0.206	0.203	-0.246
	(0.281)	(0.287)	(0.251)
lnpcl	0.778**	1.288**	-0.536
	(0.353)	(0.596)	(0.502)
lnvwp	0.264**	0.708***	1.162***
	(0.124)	(0.217)	(0.088)
lndist	-1.177***	-1.822***	-0.962***
	(0.226)	(0.299)	(0.276)
Constant	1.369	0.443	-9.278
	(3.381)	(11.31)	(5.870)
Observations	189	142	94
No. of years	28	25	28
F-stat	54.86***	51.65***	100.81***
R-squared	0.516	0.614	0.867

Note Robust standard errors in parentheses, Level of significance *** p<0.01, ** p<0.05, *p<0.1

transportation cost involved in the import. The distance between India and exporting countries negatively influence India's virtual water import. It indicates that India tends to import edible oil from countries located nearby.

Overall, the per capita gross domestic product is a significant positive driver of virtual water fluxes, especially under import law. Tamea et al. (2014) confirmed that distance is the fundamental factor controlling virtual water flows for imports and exports. In the literature of gravity model, distance is used as a proxy for transportation costs. The negative sign for an estimated parameter indicates that countries prefer to import from neighbouring countries to reduce transportation costs.

In international trade, the concept of virtual water is used to optimize the trade of commodities by considering the endowment of water resources of the nations. In line with Heckscher Ohlin (HO) theorem, virtual water trade advocates that water-abundant countries may produce commodities that use more water and export the same to water-scarce countries. Thus, it enables water-scarce nations to utilize their water resources for high productive activities. The gravity model of trade is a well-known model to identify the factors influencing virtual water flows between countries. Debaere (2014) found water as a source of comparative advantage in line with the HO theorem. A similar relationship between scare water endowments and lower net virtual water exports was found by Yang *et al* (2003) and Kumar and Singh (2005).

Wichelns (2004) suggested that other factors such as production technologies, domestic and international goods prices, and trade barriers also significantly influence virtual water trade apart from water endowment. In contrast, Ramirez-Vallejo and Rogers (2004) found no association between virtual water trade and water resource endowment. Suweis et al. (2011) describe the gross domestic product (GDP) and rainfall as the significant factors responsible for virtual water trade. Tamea et al. (2014) found that the population, per capita GDP, and distance influence virtual water trade. Instead, average income, population, value-added agriculture, and irrigation coverage significantly influenced virtual water trade (Ramirez-Vallejo and Rogers 2004, Tamea et al. 2014). Land availability limits agricultural production and virtual water trade (Kumar and Singh 2005, Fracasso 2014, Head and Mayer 2014, Zhao et al. 2019).

Conclusions

This paper has assessed the magnitude and drivers of the virtual water trade of India in the crop sector. The assessment of net virtual water trade in crop products during 1990-2017 showed that India's position has changed from the net exporter of virtual water to the net importer during 2014-2017. We used a gravity model with a panel data regression method to examine the factors influencing virtual water export and import during 1991-2017. The results showed that the distance is the primary driver of virtual water trade in all selected crops. The availability of arable land and water used in crop production are limiting factors for the production of food crops and thus act as essential factors in deciding the virtual water trade flows. The resource endowment factor for virtual water import also confirms the HO model that goods intensive in factors (land and water) are exported by countries with relatively abundant endowments.

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Appendix 1 List of food Products Traded by India

Export Products (52)		Import Products (50)	
Rice, milled	Cake, groundnuts	Oil, palm	Cake, mustard
Cake, soybeans	Lentils	Flour, Wheat	Sugar refined
Sugar refined	Oil, sesame	Oil, soybean	Cake, soybeans
Rice, broken	Linseed	Peas, dry	Flour, wheat
Oil, castor beans	Sugar nes	Oil, sunflower	Rice, milled
Groundnuts, shelled	Sunflower seed	Chick peas	Groundnuts, shelled
Maize	Peas, dry	Lentils	Sunflower seed
Cake, rapeseed	Oil, sunflower	Beans, dry	Sugar nes
Sesame seed	Oil, soybean	Oil, rapeseed	Flour, maize
Soybeans	Cake, sunflower	Barley	Cake, linseed
Wheat	Buckwheat	Cake, sunflower	Mustard seed
Flour, wheat	Cake, sesame seed	Oil, palm kernel	Groundnuts, prepared
Sugar Raw Centrifugal	Barley	Maize	Buckwheat
Chickpeas	Cake, mustard	Soybeans	Linseed
Sugar confectionery	Oats rolled	Molasses	Flour, pulses
Molasses	Cake, linseed	Sesame seed	Oil, sesame
Millet	Oats	Oilseeds nes	Flour, cereals
Flour, maize	Oil, palm	Oats rolled	Cake, rapeseed
Beer of barley	Oil, linseed	Cake, palm kernel	Rice, broken
Groundnuts, prepared	Rapeseed	Oats	Millet
Flour, cereals	Oil, safflower	Malt	Cake, groundnuts
Sorghum	Oil, rapeseed	Sugar confectionery	Oil, castor beans
Mustard seed	Oil, palm kernel	Oil, safflower	Oil, groundnut
Flour, pulses	Oil, maize	Oil, linseed	Cake, sesame seed
Malt	Rye	Beer of barley	Oil, maize
Oil, groundnut	Maple sugar and syrups		

Source FAOSTAT