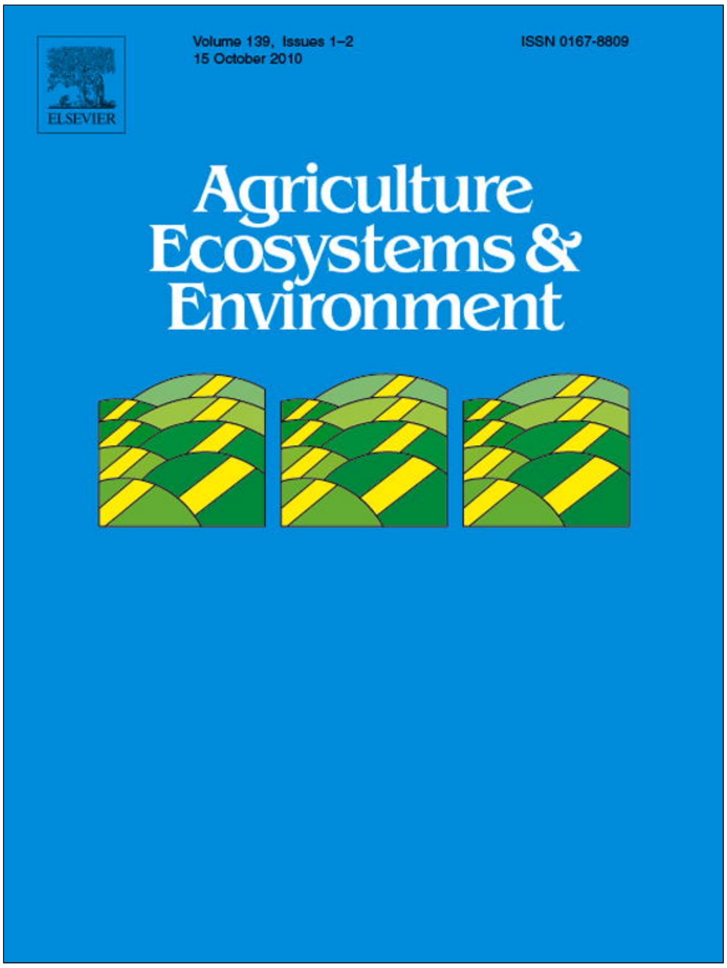
Volume 139, Issues 1–2
15 October 2010
ISSN 0167-8809
ELSEVIER
Agriculture
Ecosystems &
Environment

Agriculture, Ecosystems and Environment 139 (2010) 66–73

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Carbon footprints of Indian food items

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ARTICLE INFO

Article history:
Received 31 March 2010
Received in revised form 1 July 2010
Accepted 1 July 2010
Available online 1 August 2010

Keywords:
Food consumption
Greenhouse gas
Greenhouse gas intensity
Mitigation
Non-vegetarian meal
Vegetarian meal

ABSTRACT

Carbon emission occurs during various stages of life cycle of food products. Greenhouse gases (GHG) emission from 24 Indian food items showed that animal food products (meat and milk) and rice cultivation mostly contributed to methane (CH_4) emission, while food products from crops contributed to emission of nitrous oxide (N_2O). Emission of CO_2 occurred during farm operations, production of farm inputs, transport, processing and preparation of food. The GHG emission during the life cycle of cooked rice was 2.8 times the GHG emission during the life cycle of chapatti, a product of wheat flour. Mutton emitted 11.9 times as much GHG as milk, 12.1 times fish, 12.9 times rice and 36.5 times chapatti. As Indians mostly consume fresh foods produced locally, 87% emission came from food production followed by preparation (10%), processing (2%) and transportation (1%). For a balanced diet (vegetarian) an adult Indian man consumed 1165 g food and emitted 723.7 g CO_2 eq. GHG d^{-1}. A non-vegetarian meal with mutton emitted GHG 1.8 times of a vegetarian meal, 1.5 times of a non-vegetarian meal with chicken and an ovo-vegetarian meal and 1.4 times a lacto-vegetarian meal. Change in food habit thus could offer a possibility for GHG mitigation.

1. Introduction

The food consumption in relation to environmental impact has received political and social attention in recent years. The growth in food consumption causes increasing pressure on the environment. Research into the environmental effects of food consumption usually focuses on energy use and the production of waste and rarely has been evaluated for greenhouse gases (GHG) emission. From the food consumption, carbon dioxide (CO_2) is the most important GHG followed by methane (CH_4) and nitrous oxide (N_2O) (Kramer et al., 1999). Fuel combustion activities are the main sources of CO_2 emission, whereas animal husbandry and rice cultivation are the main sources of CH_4 emission, and the emission of N_2O is mainly from turnover of nitrogen in soil, application of N fertilizer and industry.

Carbon footprint is the total set of GHGs emission caused by a product. It is often expressed in terms of carbon dioxide equivalent of all GHGs emitted. A product's carbon footprint can be measured by undertaking a GHG emissions assessment. Once the size of a carbon footprint is known, a strategy can be devised to reduce it by technological developments, better process and product management and alternate consumption strategies. Emission of GHG occurs in various stages of the life cycle i.e., production, transport, processing and preparation of food products. Food chains around the world are responsible for a large share of total emission of GHGs. Steinfeld et al. (2006) reported that 18% of global GHGs emission could be attributed to animal products alone. For the European Union, about 29% of GHG emissions are related to food consumption (EIPRO, 2006). Agriculture contributes about 13.5% of global emission (IPCC, 2007). In India, this sector contributes 18% of the total GHG emission (INCCA, 2010). The emissions from agriculture are primarily due to methane emission from enteric fermentation in ruminants (63%) and rice fields (21%), nitrous oxide from application of N through manure and fertilizer to agricultural soil (13%) and manure management and burning of crop residue (2.7%).

The Inter-Governmental Panel on Climate Change (IPCC) in its Fourth Assessment Report (AR4) pointed out that lifestyle changes and behaviour patterns can contribute to climate change mitigation across all sectors. In this context it is argued that reducing animal protein consumption can bring down GHG emission. Worldwide animal protein is being consumed at an increasing rate. Earlier this trend was limited to the developed world. But with rapid increase in purchasing power in recent decades in developing countries, animal protein consumption has gone up substantially. This trend will not only cause a major setback to global food security but also add to mounting emission of GHG.

The objectives of this article were to calculate carbon footprint of Indian food consumption, analyze the differences in GHG emission from vegetarian and non-vegetarian foods and estimate GHG emission at current and projected levels of food consumption in India. This will enable individuals to calculate carbon emission from the food they consume and develop safer options. Furthermore, the article indicates how these insights may be

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doi:10.1016/j.agee.2010.07.002

Table 1
Ingredients for one serving-portion of various food items commonly consumed in Indian households.

Food item	No./quantity	Ingredient (fresh weight, g)				Water for preparation (g)	Product fresh weight (g)	Product dry weight (g)
		Main	Oil	Vegetable	Spice/sugar			
Chapatti[a]	4	100				40	140	90
Bread[a]	2	60				20	80	54
Paratha[a]	2	100	5	50	5	60	220	144
Burger[a]	1	75	15	50	5	25	170	131
Rice (ordinary)	1 plate	100				45	145	88
Rice (basmati)	1 plate	100				40	140	88
Dosa[a]	1	50	5		5	50	110	53
Idli[a]	1	25				25	50	22
Pulse	1 cup	30	5		5	100	140	37
Sambar[a]	1 cup	30	5	15	5	100	155	51
Potato	1 cup	120	5		5	25	155	26
Cauliflower	1 cup	100	5		5		110	17
Brinjal	1 cup	100	5		5		110	13
Poultry meat	1 plate	100	10		10		120	39
Mutton	1 plate	100	20		10		130	39
Fish	2 pieces	100	10		5		115	33
Egg	1	50					50	25
Omlette	1	50	3		3		56	25
Milk	1 glass	250			5		255	33
Curd[a]	1 cup	100					100	10
Lassi[a]	1 cup	50			15	50	115	7
Butter[a]	1 spoon	10					10	8
Apple	1	100					100	15
Banana	1	100					100	10

Source: updated from Khanna et al. (1997).
[a] Main ingredients of these food items are wheat, rice, pulse and milk, respectively.

translated into GHG mitigation options with regard to food consumption.

2. Materials and methods

2.1. Common food items in India and their ingredients

India, being diverse in climate and culture, has wide diversity in consumption of food. For example, rice is preferred as a staple food in the eastern and southern regions whereas wheat is the staple food in the northern region. However, because of more urbanization and increasing income, food habits are changing and today's cosmopolitan Indians consume diverse food items. For this research the GHG emission in the various stages of the life cycle of 24 most common Indian food products was included. Table 1 shows the ingredients used to prepare these products. Requirement of primary and secondary ingredients for one serving-portion of various food items was calculated based on Khanna et al. (1997).

2.2. Emission of GHG during the life cycle of various food items

Basically four stages of life cycle of food products i.e., production, processing, transportation and preparation were considered in this study. The means of purchasing and storing by individual households were not considered. Similarly losses occurring during storage and handling during production were not accounted for. Food products from animal determined the CH_4 emission, while food products from crop determined the emission of CH_4 (from rice cultivation) and N_2O (from all crops). Emission of CO_2 occurred during farm operations, production of farm inputs, transport, processing and preparation of food.

2.2.1. Emission of GHG during production of the food

Data used to calculate CH_4 and N_2O emission factors of the main ingredients of the food products are given in Table 2. Methane emission for rice production (M_rice, kg kg^{-1}) was calculated using the following equation.

$$M\_rice = \frac{E\_rice}{P\_rice}$$

where E_rice is CH_4 emission (3.64 Mt) from 44.25 Mha of Indian rice fields (NATCOM, 2004) and P_rice is production of rice (93.4 Mt) (MoA, 2006a).

Emission of GHGs (except methane from rice) from crop production was calculated from the data generated through a series of field experiments conducted at Indian Agricultural Research Institute, New Delhi to quantify the GHG emission related to production of various crops (Pathak et al., 2002, 2003, 2005; Majumdar et al., 2002; Bhatia et al., 2004; Jain et al., unpublished).

Table 2
Emission of greenhouse gases due to production of various food products from crop and animal.

Crop/animal product	GHG emission (g kg^{-1})			
	CH_4	N_2O	CO_2	GWP (CO_2 eq.)
Wheat	0.0	0.3	45.0	119.5
Rice	43.0	0.2	75.0	1221.3
Rice, basmati	53.7	0.3	82.5	1515.4
Pulse	0.0	0.8	83.3	306.8
Potato	0.0	0.1	10.0	24.9
Cauliflower	0.0	0.1	13.3	28.2
Brinjal	0.0	0.1	12.5	31.1
Oilseed	0.0	1.3	50.0	422.5
Poultry meat	0.0	2.7	50.0	846.5
Mutton[a]	482.5	0.0	0.0	12,062.7
Egg	0.0	2.0	1.0	588.4
Milk[a]	29.2	0.0	0.0	729.2
Banana	0.0	0.2	10.0	71.6
Apple	0.0	1.0	41.7	331.4
Spice	0.0	2.5	100.0	845.0
Fish	25.0	0.3	18.8	718.3

Source: calculated from Bhatia et al. (2004), NATCOM (2004), Chhabra et al. (2009), Pathak et al. (2009b) and Jain et al. (unpublished).
[a] Emission of nitrous oxide and carbon dioxide for milk and mutton production was not considered as buffalo, cattle and goat in India are mostly fed with by-products of crops.

Cattle and buffalo are the main milk-producing animals in the country constituting 61% of the total livestock population (NATCOM, 2004). Besides poultry meat, mutton is the most common source of animal meat consumed in India. In the present study, therefore, milk production from cattle and buffalo and meat production from poultry and goat were considered. The data on GHG emission from livestock were obtained from Chhabra et al. (2009), who compiled data from various sources (ALGAS, 1998; NATCOM, 2004; Swamy et al., 2004; Singhal et al., 2005) to estimate CH_4 emission from different categories of ruminants. Emission of CH_4 from ruminants was calculated by dividing total emission of methane from the ruminants with their respective population (17th Livestock Census, MoA, 2006b) and in all the cases weighted average values were used for analysis.

Emission of CH_4 from milk production (M_milk, kg L^{-1}) was calculated using the following equation.

$$\text{M\_milk} = \frac{\text{E\_milk}}{\text{P\_milk}}$$

where E_milk is average CH_4 emission (kg d^{-1}) from lactating crossbred, non-descript cow and lactating buffalo, respectively; and P_milk (L d^{-1}) is average milk production of lactating animals (MoA, 2006b). Average CH_4 emission (E_milk) from lactating bovines (crossbred cows, non-descript cows and buffaloes) was calculated by dividing total emission of methane from lactating bovines with total population of lactating bovine (Chhabra et al., 2009). The average milk produced by crossbred cows, non-descriptive cows and buffalos in India are 6.5, 1.9 and 4.2 L d^{-1}, respectively (MoA, 2006b). These quantities are much less than the milk produced by cattle in the developed countries mainly because of poor quality of feed available (IPCC, 2007).

Emission of CH_4 from mutton production (M_mutton, kg kg^{-1}) was calculated using the following equation.

$$\text{M\_mutton} = \frac{\text{E\_mutton}}{\text{W\_mutton}} \times 0.50$$

where E_mutton is CH_4 emission (kg $year^{-1}$ $goat^{-1}$), W_mutton (kg $year^{-1}$) is the body weight of goat at the time of slaughter, and 0.50 is the fraction of mutton to total body weight. Average CH_4 emission (E_mutton) from goat was calculated by dividing total emission of methane from goat per year (Chhabra et al., 2009) with total population of goat (17th Livestock Census, MoA, 2006a,b). Average age for slaughtering goat was taken as 12 months and average body weight of the animal at the time of slaughter was taken as 15 kg.

Emission of N_2O and CO_2 for milk and mutton production was not considered as buffalo, cattle and goat in India are mostly fed with by-products of crops such as wheat straw, rice straw and oilseed cake. Emission of N_2O and CO_2 from production of these by-products of crops have been considered for the main products i.e., wheat, rice and oilseed.

Emission of N_2O from poultry meat production (N_poultry, kg kg^{-1}) was calculated using the following equation.

$$\text{N\_poultry} = \frac{\text{F\_poultry} \times \text{N\_feed}}{\text{W\_polutry}} \times 0.55$$

where F_poultry is feed grain required (kg $year^{-1}$ $bird^{-1}$) by broilers, N_feed is N_2O emission from feed grain (maize and sorghum grain) production (kg kg^{-1}), W_poultry is the body weight of a bird (kg) and 0.55 is the fraction of poultry meat to total body weight. It was assumed that the bird is slaughtered at 7 weeks age and average weight of the bird is 1.8 kg. Emission of N_2O from maize and sorghum was calculated by dividing N_2O emission per hectare of cropped land by grain yield (Jain et al., unpublished).

Emission of nitrous oxide from egg production (N_egg, kg kg^{-1}) was calculated using the following equation.

$$\text{N\_egg} = \frac{\text{F\_poultry} \times \text{N\_feed}}{\text{W\_egg}}$$

where F_poultry is feed grain required (kg $year^{-1}$ $bird^{-1}$) by layers, N_feed is N_2O emission from feed grain (maize and sorghum grain) production (kg kg^{-1}), W_egg is the weight of egg (kg) laid by a bird in a year. The W_egg was calculated by multiplying No. of eggs laid by a bird in a year with weight of an egg (50 g).

2.2.2. Emission of GHG during transportation, processing and preparation of food

Emission of CO_2 (Table 2) for various farm operations (tillage, sowing, irrigation, harvesting and transport to farm) and production of farm inputs (fertilizer and pesticides) were based on Pathak and Wassmann (2007) and Pathak et al. (2009b). Another important process which emits CO_2 during the life cycles of food production is transport between farm and industry and between industry and consumer. Processing and preparation also emitted CO_2 and were related to the use of energy. In India, most of the staple food items are consumed locally and main transport occur from rural areas to cities. A distance of 200 km was taken as the average transportation distance through road with average diesel consumption of 15 km L^{-1}. Contrary to the developed countries, most of the common Indian foods are not processed and prepared directly for consumption. Total emission of CO_2 was calculated from the amount of diesel used for transport and processing, and liquid petroleum gas (LPG) for preparation of food. Each liter of diesel consumed would emit 2.6 kg CO_2 (Pathak et al., 2009a) whereas 1 kg LPG used would emit 2.95 kg CO_2 (Thomas et al., 2000). The rate of burning LPG for conventional domestic LPG stove was taken as 0.13 kg h^{-1} (Pantangi et al., 2007).

2.3. Emission of GHGs for a balanced diet and common Indian meals

Emission of GHG for balanced diet for adult man and woman at moderate level of work was calculated based on their respective diet requirements (Khanna et al., 1997) and associated GHG emission for production, processing, transport and preparation of respective food items. A comparison of GHG emission was also made for five common diets i.e., vegetarian, lacto-vegetarian (vegetarian with milk), ovo-vegetarian (non-vegetarian with egg), non-vegetarian with poultry meat and non-vegetarian with mutton.

2.4. GHG emission intensity of the food items

The emission intensity for calorific value of food was calculated using the following equation.

$$\text{GWP\_Cal} = \frac{\text{GWP\_ food}}{\text{Cal\_food}}$$

where GWP_Cal is the global warming potential (GWP) per calorie food intake (g CO_2 eq. cal^{-1}), GWP_ food is GWP of food items (g CO_2 eq.) and Cal_food is the calorific value of food items (cal).

The GHG intensity for price was calculated using the following equation.

$$\text{GWP\_Rs} = \frac{\text{GWP\_ food}}{\text{Rs\_food}}$$

where GWP_Rs is GWP per Rs. food price, GWP_food is GWP of food items (g CO_2 eq. kg^{-1}) and Rs_food is price of food items (Rs. kg^{-1}). Price of food items was obtained from their current market prices. Some food items such as egg are sold in numbers rather than

Table 3
Emission of greenhouse gases in various stages of life cycle of food items.

Food	GHG emission (g kg^{-1} fresh product)						GWP (g CO_2 eq. kg^{-1} fresh wt.)	GWP (g CO_2 eq. kg^{-1} dry wt.)
	Production			Processing	Transport	Preparation		
	CH_4	N_2O	CO_2	CO_2	CO_2	CO_2		
Chapatti	0.0	0.2	32.1	0.0	5.2	160.0	250.6	389.8
Bread	0.0	0.2	32.1	100.0	7.8	64.0	257.2	381.0
Paratha	0.0	0.1	21.7	0.0	7.8	192.0	261.7	399.8
Burger	0.0	0.1	21.6	100.0	7.8	32.0	204.3	266.2
Rice (ordinary)	21.5	0.1	37.5	0.0	5.2	96.0	711.9	1617.9
Rice (basmati)	26.9	0.2	41.3	0.0	5.2	96.0	858.9	1952.0
Dosa	19.5	0.1	34.8	0.0	7.8	160.0	729.3	1519.3
Idli	21.5	0.1	37.5	0.0	7.8	64.0	682.5	1551.0
Pulse	0.0	0.2	18.6	0.0	7.8	128.0	207.9	790.9
Sambar	0.0	0.2	17.1	0.0	5.2	128.0	199.3	610.7
Potato	0.0	0.1	8.5	0.0	10.4	96.0	132.0	787.0
Cauliflower	0.0	0.1	12.9	0.0	10.4	96.0	138.4	922.7
Brinjal	0.0	0.1	12.1	0.0	10.4	96.0	141.0	1175.3
Poultry meat	0.0	2.1	39.2	0.0	15.6	128.0	801.1	2704.9
Mutton	357.4	0.0	0.8	0.0	15.6	192.0	9149.3	32,081.9
Fish	20.0	0.2	15.8	0.0	15.6	160.0	756.5	2865.7
Egg	0.0	2.0	1.0	0.0	15.6	64.0	668.0	1335.9
Omlette	0.0	1.8	1.3	0.0	15.6	64.0	608.7	1383.5
Milk	28.6	0.0	0.5	0.0	15.6	32.0	766.8	5898.1
Curd	29.2	0.0	0.0	0.0	15.6	0.0	744.8	7448.3
Lassi	12.7	0.0	1.5	0.0	15.6	0.0	345.3	6109.7
Butter	29.2	0.0	0.0	250.0	18.2	0.0	997.4	1187.4
Apple	0.0	1.0	41.7	0.0	26.0	0.0	357.4	2382.6
Banana	0.0	0.2	10.0	0.0	26.0	0.0	97.6	975.9

weight. To maintain the uniformity of the units for quantifying GHG intensity, no. of eggs were converted into weight of eggs (1 egg = 50 g).

Emissions of GHG due to food consumption in India at base year (2004–2005) and projected demand (2011–2012 and 2020–2021) were also calculated taking into account the projected demand of various food products (Joshi et al., 2009) and associated GHG emission.

3. Results and discussion

3.1. Emission of GHG due to production of the food items

Production of food products varied considerably in GHG emission (Table 2). For example, emission of GHG from production of ordinary rice was about 10.2 and 43.3 times higher than production of wheat and vegetables, respectively. For the production of basmati rice, the emission was 1.2 times higher than that of ordinary rice. Higher emission in rice was because of CH_4 emission under anaerobic soil condition whereas wheat, vegetables and other crops are grown in aerobic soil conditions and there is no CH_4 emission. Sonesson et al. (2009) reported total emission of GHG for milled rice to be 6 times higher than the wheat flour. In general, production of fruits and vegetables are associated with fairly low emissions. Potato and other root vegetables have high productivity, resulting in low emission of GHG per unit food product.

Production of food (meat and milk) from animal emitted larger amount of GHG compared to food from crops because of emission of methane by ruminants (Table 2). The nature of GHG also varied for different food items. The food products from animal such as mutton, poultry meat, dairy products and fish dominated the CH_4 emission. On the other hand, the food products from crop contributed to N_2O emission except rice, which contributed to CH_4 as well as N_2O emission. Application of synthetic nitrogen fertilizers in agriculture was responsible for a major part of the N_2O emission.

3.2. Emission of GHG during the life cycle of the food items

Table 3 presents data on GWP during the life cycle of various food items on fresh and dry weight basis. The GWP of food items was larger on dry weight basis than that with fresh weight basis. However, as the foods are generally consumed fresh, the results

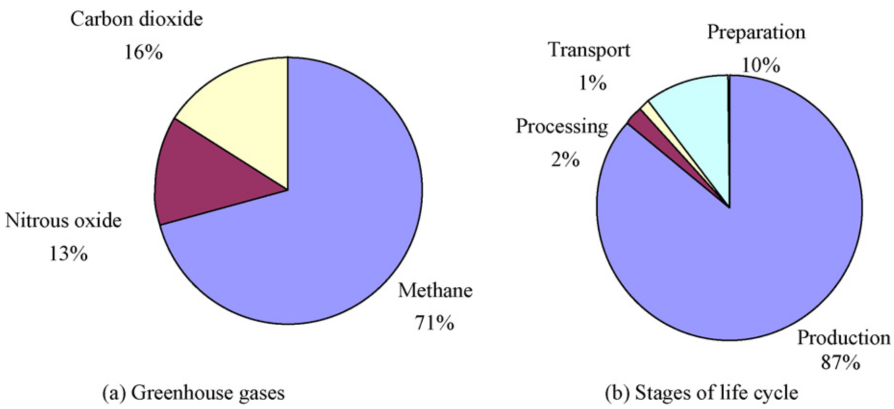

Fig. 1. Relative contribution of (a) various greenhouse gases and (b) various stages of life cycle of Indian food items towards global warming.

Table 4
Balanced diet requirement for adult man and woman per day and associated greenhouse gas emission at moderate level of work.

Food	Man				Woman			
	Diet requirement (g)[a]		GWP (g CO_2 eq.)		Diet requirement (g)[a]		GWP (g CO_2 eq.)	
	Veg.	Non-veg.	Veg.	Non-veg.	Veg.	Non-veg.	Veg.	Non-veg.
Wheat	225	225	78.9	78.9	175	175	61.4	61.4
Pulse	80	65	23.3	18.9	70	55	20.4	16.0
Rice	250	250	355.9	355.9	175	175	249.2	249.2
Green vegetable (cauliflower)	125	125	19.0	19.0	125	125	19.0	19.0
Other vegetables (brinjal)	75	75	11.6	11.6	75	75	11.6	11.6
Roots and tubers (potato)	100	100	17.1	17.1	75	75	12.8	12.8
Milk	200	100	156.4	78.2	200	100	156.4	78.2
Apple	30	30	10.7	10.7	30	30	10.7	10.7
Sugar	40	40	33.8	33.8	30	30	25.4	25.4
Oil	40	40	16.9	16.9	40	40	16.9	16.9
Egg	–	30	–	20.0	–	30	–	20.0
Mutton	–	30	–	370.5	–	30	–	370.5
Total	1165	1110	723.7	1031.7	995	940	583.8	891.8

[a] Fresh weight, updated from Khanna et al. (1997) and Gopalan et al. (1978).

have been discussed on fresh weight basis only. The food products differed considerably in terms of GWP. Life cycle of rice (ordinary and basmati) emitted 2.8–3.4 times GHG than chapatti (Table 3). Emission of CH_4 during the cultivation of puddled transplanted rice was responsible for the large difference in the GHG emission between rice and chapatti. Such differences also occurred in other food categories. In terms of GWP, mutton contributed 11.9 times that of milk, 12.1 times that of fish, 12.9 times that of rice and 36.5 times that of chapatti during their respective life cycles (Table 3). On an average, CH_4 contributed 71% of the GWP for food consumption whereas CO_2 and N_2O contributed 16% and 13%, respectively (Fig. 1a).

As Indians mostly consume fresh foods produced locally, 87% of the emission came from food production followed by preparation (10%), processing (2%) and transportation (1%) of food (Fig. 1b). In Europe and America, where processed foods are more common, the share of transportation and processing to GWP is more (Sonesson et al., 2005). Worldwide transportation contributes 14% of GHG emission for meat production and in the United Kingdom contribution of transportation was 8% for consumption-oriented purposes (Garnet, 2007). In Sweden transportation contributed 16% and 31% of the total GHG emission for carrots and potatoes, respectively (Kanyama, 1998).

3.3. *Carbon footprint of balanced diet*

A balanced diet is one which contains different foods in quantities and proportion that the need for calories, minerals, vitamins, carbohydrate, fat and other nutrients is met to withstand short duration of leanness (Gopalan et al., 1978). Taking into account the foods which commonly form part of the Indian diets, suggested balance diets for man and women are given in Table 4. For a balanced diet (vegetarian), an adult Indian male consumed 1165 g food d^{-1} and emitted 723.7 g CO_2 eq. GHG d^{-1} (Table 4). For a vegetarian adult female the emission was 20% lower. Emission of GHG was 40% more for a non-vegetarian meal. For the developed countries per capita GWP for food consumption is about 1200–1500 g CO_2 eq. i.e., 2 times that of Indian emission (Sonesson et al., 2009).

In a common lacto-vegetarian meal rice contributed the largest amount of GHG (49%) followed by milk (22%) (Fig. 2a). In a non-vegetarian meal contribution of mutton was the largest (35%) towards GHG emission, closely followed by rice (34%) (Fig. 2b). Kramer et al. (1999) showed that meat and dairy products account for 28% and 23% of GHG emission, respectively in Dutch food.

3.4. *Carbon footprint of common Indian meals*

Comparison of GHG emission from five common meals showed that a non-vegetarian meal with mutton emitted highest amount of GHG, 1.8 times than the vegetarian meal, 1.5 times of a non-vegetarian meal with chicken and an ovo-vegetarian meal and 1.4 times a lacto-vegetarian meal (Fig. 3). Mutton consumption causes more GHG emission compared to consumption of foodgrain and poultry products. A study from Spain and Sweden also showed that vegetarian meals were associated with less environmental impact than meals with animal protein (Sonesson et al., 2009). These data support in favour of vegetarians for reducing GHG emission. This could, however, be true if the animal protein is substituted by crop or poultry products. Substitution by milk will be less effective as it would increase GHG emission compared to vegetarian meal (without milk). But in India and in most other countries, milk is an integral part of vegetarian diet. When milk was included in the vegetarian meal (lacto-vegetarian), GHG emission increased by 1.3 times. Production of milk emitted considerable amount of GHG (Table 2). Therefore, for a balanced diet substitution of milk in vegetarian meal by legumes, or soy milk for protein could be an option for GHG emission mitigation. However, as milk also supplies minerals and vitamins, while replacing milk with other sources of protein, supply of these nutrient elements need to be considered.

3.5. *GHG intensity and annual GWP of food consumption in India*

The GWP per calorie food intake was highest for mutton (5301 g CO_2 eq. cal^{-1}) followed by egg and milk and the lowest was for wheat (Table 5). The GHG intensity for price was also highest for mutton (56 g CO_2 eq. $Rs.^{-1}$) followed by milk (36 g CO_2 eq. $Rs.^{-1}$) and wheat (19 g CO_2 eq. $Rs.^{-1}$) (Table 5).

On a national level, food consumption in India during 2004–2005 was 493.2 Mt, which contributed 397.2 Mt CO_2 eq. In the years 2010–2011 and 2020–2021 the food demand would increase to 593.1 and 600.1 Mt and the GWP would be 495.7 and 642.0 Mt CO_2 eq., respectively (Table 6).

3.6. *Mitigation of GHG emission from food consumption*

The results of the GHG emission analysis showed variations in GHG emission from food within food products offering possibilities to reduce the GHG emission from food consumption. An example could be a shift from animal food products to crop food products. Within crop foods, products based on rice (rice, dosa and idli) would

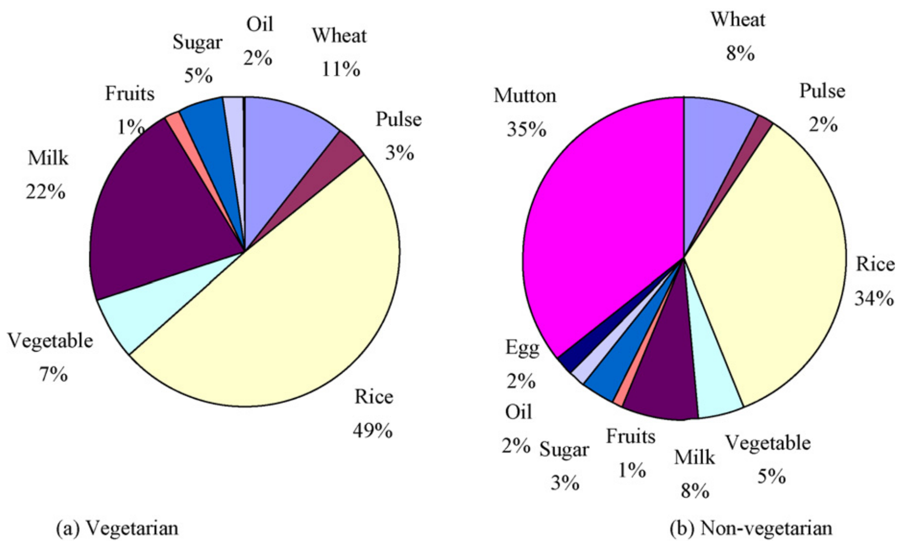

Fig. 2. Relative contribution of various food items to greenhouse gas emission in balanced vegetarian and non-vegetarian diets.

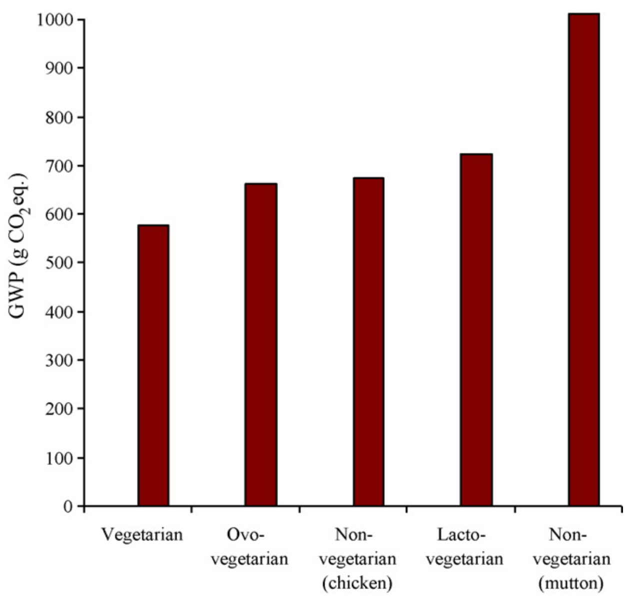

Fig. 3. Global warming potential of various vegetarian and non-vegetarian meals in India.

emit more GHG compared to wheat-based products (chapatti and bread). Therefore, to mitigate GHG emission within crop-based food products either consumption of rice is to be reduced or rice should be grown in a different way. Aerobic rice or direct-seeded rice is a good example of growing rice differently. Studies have shown that the GWP of direct-seeded rice was only 25% of that of the conventional puddled transplanted rice (Pathak et al., unpublished).

For the substitution of food products, however, it is very important to pay attention to the nutritive values of foods and getting a balanced diet. Meat consumption could be substituted by other protein, such as pulse and vegetables. However, substitution of meat by dairy products (milk) is less effective than substitution by the vegetables and pulses. In addition, other behavioural options are conceivable (e.g. substitution of tinned, bottled, or frozen vegetables for fresh vegetables) for mitigation of GHG emission. However, technical options in the life cycle of food products to reduce the GHG emissions of food products are also very important but lie outside the scope of this article.

Worldwide a considerable research was carried out on the GHG emission from household food consumption. Coley et al. (1998) calculated energy intensities in the Netherlands and Biesiot and Moll (1995) estimated the distribution of the energy use of typical diet in the United Kingdom and observed a potential for fossil-fuel-related GHG reduction potential. Kramer et al. (1999) analyzed differences in GHG intensities within food products and showed possibilities for GHG reduction in Dutch households by changing their expenditure on food products. Higher emission from animal products has also been reported from New Zealand and Europe. For example, Sonesson et al. (2009) reported the emission of GHG from milk to be 3.1–3.8 kg CO_2 eq. kg^{-1} on 70% water-content basis. Wallén et al. (2004) compiled data from a variety of sources to show the emis-

Table 5
Emission of greenhouse gases per calorie food consumption and their emission intensity.

Food	GWP of food (g CO_2 eq. kg^{-1})	Food value (cal kg^{-1})[a]	Emission intensity for food value (g CO_2 eq. cal^{-1})	Price of raw food (Rs. kg^{-1})[b]	Emission intensity for price (g CO_2 eq. $Rs.^{-1}$)
Wheat	351	3410	0.10	18	19
Rice	1424	3330	0.43	25	57
Pulse	970	3250	0.30	80	12
Vegetable	171	300	0.57	25	7
Milk	782	680	1.15	25	31
Apple	357	560	0.64	80	4
Sugar	845	4000	0.21	40	21
Oil	423	9000	0.05	70	6
Mutton	12,352	2000	6.18	240	51
Egg	668	1750	0.38	70	10

[a] Source: Khanna et al. (1997).
[b] Current (March, 2010) price of the commodities at Delhi market.

Table 6
Annual demand for various food products and the resultant GWP in India.

Food	Demand (Mt)[a]			GWP (Mt CO_2 eq.)		
	2004–2005	2011–2012	2020–2021	2004–2005	2011–2012	2020–2021
Wheat	78.0	81.0	83.0	27.4	28.4	29.1
Rice	98.0	125.0	173.0	139.5	178.0	246.3
Pulse	14.0	16.0	16.0	13.6	15.5	15.5
Vegetable	91.0	108.0	127.0	15.5	18.4	21.7
Milk	91.0	114.0	142.0	71.2	89.2	111.1
Apple	53.0	67.0	86.0	18.9	23.9	30.7
Sugar	24.0	27.0	31.0	20.3	22.8	26.2
Oilseed	36.0	44.0	54.0	15.2	18.6	22.8
Mutton	6.0	8.0	11.0	74.1	98.8	135.9
Egg	2.2	3.1	4.1	1.5	2.0	2.7
Total	493.2	593.1	727.1	397.2	495.7	642.0

[a] Fresh weight, source: Joshi et al. (2009).

sions during the production, processing and distribution of a range of commonly consumed foods in Sweden and concluded that milk products and meat contributes 43% to the total GWP from food consumption. In UK, food commodities with low emission (less than 1 kg CO_2 eq. kg^{-1}) are the crop commodities with high yields and low inputs, such as apple, potato, animal feed crops, wheat, and onion. Food commodities with medium emissions (between 1 and 5 kg CO_2 eq. kg^{-1}) tended to be livestock or manufactured products such as milk whereas food commodities with high emissions (over 5 kg CO_2 eq. kg^{-1}) are livestock products and highly manufactured foods such as pig meat and beef (DEFRA, 2009).

The calculations of GHG intensities of food products provided interesting information which can be very helpful to formulate the most effective options to reduce the GHG emissions related to household food consumption. The contribution of the food products to the other GHG emissions vary strongly, mainly due to differences in agricultural processes. In contrast to CO_2, the contributions of CH_4 and N_2O from the food categories show different pictures. Meat and dairy products contribute much to the CH_4 emissions, and agricultural crop production contributes much to the N_2O emissions. The agricultural sector also dominates the CH_4 and N_2O emissions of household food consumption. Consequently the other stage of the food product life cycle contributes less to the GHG emissions of food consumption.

The differences in GHG emissions offer possibilities for reduction options. Households could reduce the GHG emissions from food consumption by changing their consumption pattern. This research showed that at the level of household food consumption, options to reduce GHG emissions could consist of substitution from animal food product to crop food product. Shifting from products from ruminants to poultry would also be useful to mitigate GHG emission.

4. Conclusions

This research indicated that change in food habit offers possibilities for GHG mitigation. Food product selection that favours items with lesser environmental consequences could be part of the attempts to reduce GHG emissions. Some options to reduce the GHG emissions of food consumptions are consumption of locally produced foods; less mutton consumption; substitution of meat and milk by other vegetable protein. However, in case of food product substitution, besides the calorific value and GHG emission, the nutritional values (vitamins, proteins and minerals) of food product are very important. In order to efficiently workout "climate smart diets" more knowledge is needed about life cycle impact of single products and connections between diets and how the food chain is affected by changed diets. The calculated GHG intensities of food products are typical for the Indian situation and these could not directly be used by other countries to formulate options to reduce the emissions to a certain level. However, the results could be used for other countries as an indication of the GHG emission of its national food consumption and to identify hot spots.

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