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Original Article

Impact of different macronutrient definitions and energy conversion factors on energy supply estimations

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Abstract

The magnitude of differences in energy supply using different definitions for carbohydrates and protein as well as different energy conversion factors was investigated. Food supply data for 1999–2001 from FAOSTAT were used for nine countries with different types of diets. Nutrient values were derived from USDA and the British food composition tables for three definitions of carbohydrate (total, available by difference, available as monosaccharide equivalents), three protein definitions (nitrogen (N) × Jones factors, N × 6.25, sum of amino acids), fat, and two dietary fibre definitions (AOAC, non-starch polysaccharide). Then three sets of energy conversion factors were applied (Merrill & Watt, general Atwater with/without energy value for fibre, and gross energy—GE). Using the same nutrient definitions, differences between general and specific Atwater factors accounted for 50–320 kJ/capita/day (10–75 kcal/capita/day) and for 290–1500 kJ/capita/day (70–360 kcal/capita/day) between GE and metabolizable energy supply calculations. Protein definitions have a minor impact on per capita energy supply values. They generate differences of less than 1%, or 4–105 kJ (1–25 kcal), with N × 6.25 values providing the highest values, followed by Jones factors and the sum of amino acids. The largest differences observed in per capita energy supply calculations are due to carbohydrate definitions. Differences of 3.5–8% or 330–780 kJ/capita/day (80–190 kcal/capita/day) are observed between total and available carbohydrates as monosaccharide equivalents within the general Atwater system. Differences in energy supply between total and available carbohydrates could be minimized by applying an energy factor of 8 kJ/g (2 kcal/g) for dietary fibre, resulting in a higher energy supply of 100–250 kJ/capita/day (25–60 kcal/capita/day) or 1–2%. Differences in energy supply are less influenced by the energy factors as such than by the nutrient definition used, especially for carbohydrates. Differences in energy supply of up to 780 kJ/capita/day (160 kcal/capita/day) or 8% may be statistically relevant and might change research results, estimates of the dietary energy supply and consequently the estimation of the prevalence of undernourishment which may affect nutrition

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program and policies. Global harmonization of macronutrient definitions and energy factors is important to achieve unambiguous and comparable macronutrient and energy values among countries.

Keywords: Energy conversion; Macronutrient definition; Energy supply

1. Introduction

Energy and nutrient values of foods are mainly used to translate food intakes into intakes of food components. These data are important for nutritional assessment, research linking diet and disease, health and nutrition policies and programs, agriculture policies, food labelling and consumer education. With regard to public health, energy intakes are compared to energy requirements before decisions are made regarding health and nutrition policies and programs. In nutritional epidemiology, nutrient and energy intakes are used to calculate disease risk (Willett, 1998). In food labelling, nutrients and energy conversion factors are defined by national (e.g., (US FDA, 2002)), regional (e.g., EU, 1990) or international (e.g., Codex Alimentarius, 2001) regulations and recommendations. Ideally, food composition data should be comparable between food composition databases and food labelling regulations which is not always the case, even at national level (e.g., in the USA).

Food energy can be measured by bomb calorimetry but usually is calculated by applying a set of energy conversion factors of energy-providing nutrients: protein, carbohydrate, fat, and alcohol, and occasionally some minor constituents. Throughout the world, different sets of energy conversion factors are used as well as different nutrient definitions, and both can have an impact on the energy values of foods and energy intake calculations. In this article, we investigated the impact of different macronutrient definitions, together with different energy conversion factors on per capita energy supply. This article is divided in two parts. In the first one, definitions of macronutrients and energy conversion factors will be discussed and in the second part, some of these definitions will be selected to investigate their impact on per capita energy supply.

2. Part I: Definitions of macronutrients

2.1. Protein

For most food composition databases and for most food labelling purposes, protein is calculated from total nitrogen (N) measured by the Kjeldahl (1883) method. On average, protein contains 16% N; therefore, the nitrogen content can be multiplied by 6.25 to get an approximate protein value (Jones et al., 1942). Acknowledging that this multiplication is only an approximation, Jones (1931) developed nitrogen conversion factors for specific foods to take the N content of different proteins into account. These factors have been widely recognized and used, and have been adopted by the United Nations Food and Agriculture Organization (FAO) and the World Health Organization (WHO) (FAO/WHO Expert Group, 1973). Some countries have modified slightly some of these conversion factors in their food composition databases such as Italy, Sweden, Denmark, France and Germany (Deharveng et al., 1999). Not all of the nitrogen is part of protein, particularly in legumes, and this non-protein nitrogen (free amino acids, small peptides, urea, nucleotides, etc.) is sometimes subtracted from the total nitrogen before applying the nitrogen conversion factor.

Protein is also calculated using amino acid data together with the ratio of total amino acid residues to amino acid nitrogen. Some researchers suggest that the protein conversion factors should be lowered based on examination of these data. Sosulski and Imafidon (1990) suggest a mean conversion factor of 5.7 for mixed foods; Salo-Väänänen and Koivistoinen (1996) propose a mean conversion factor of 5.33. Both groups propose individual factors for foods and food groups.

In practice, there are at least 13 ways to obtain protein values (see Table 1). Protein values differ slightly according to the different definitions, with N × 6.25 as the nitrogen conversion factor yielding in most cases the highest value. If the lower nitrogen conversion factors would be adopted, protein values of foods and diets would drop considerably as well as the value of energy from protein.

Other important aspects of the utilization of protein in the body are protein quality, the matrix of the food, and the metabolic energy loss for the synthesis of peptide bonds and nucleotides. This information is usually not reported in food composition databases but is important for protein requirement comparisons and energy availability.

2.2. Carbohydrates

For some purposes, carbohydrates are grossly classified as available and unavailable carbohydrates, where the unavailable carbohydrate is considered as dietary fibre. Carbohydrates can chemically or structurally be grouped according to the degree of polymerization into sugars (mono- and disaccharides and polyols), oligosaccharides and polysaccharides. Oligosaccharides (3–9 saccharides) include malto-oligosaccharides (e.g., maltodextrin) and other oligosaccharides

Table 1
Basis for protein calculation

1. Calculation based on amino acid determination
Sum of amino acids (minus additional water)
2. Calculation based on nitrogen (N) determination multiplied by nitrogen conversion factor
Selection of nitrogen value
Total N (analysed through Kjeldahl)
Protein N
Amino N
Selection of nitrogen conversion factor (NCF)
N × 6.25
N × Jones factor
N × adapted Jones factors
N × lowered factors (5.7 or 5.33 together with specific factors)

(e.g., raffinose, stachyose). They are often minor components in foods and are therefore not included in some carbohydrate definitions. Oligosaccharides are less well absorbed in the small intestine but are fermented in the colon which raises the question to define them rather as dietary fibre (Slavin, 2003). The polysaccharides are separated into starch and non-starch components. The starch fraction includes amylose, amylopectin, modified and resistant starch. The non-starch fraction includes cellulose, hemicellulose, pectins and hydrocolloids (FAO/WHO, 1998).

In food composition databases, the term 'carbohydrate' is rarely used alone or without explanation. Table 2 shows the carbohydrate terms, their definitions and the INFOODS TAGNAME (Klensin et al., 1989). Total carbohydrate by difference (CHOCDF) is calculated as 100 g food minus the sum of grams of water, protein, fat, alcohol and ash. Total carbohydrate can also be based on the sum of analysed carbohydrate fractions (CHOCSM). Available carbohydrate by difference (CHOAVLDF) is calculated by subtracting from total carbohydrate the dietary fibre value. Its value would differ based on whether crude fibre, total dietary fibre (TDF), or non-starch polysaccharides (NSP) were subtracted. It is assumed that the values are analysed if available carbohydrate 'as monosaccharide equivalents' (CHOAVLM) is used or 'by summation' or 'by weight' (also called 'anhydrous form'), identified by the TAGNAME 'CHOAVL'. 'By weight' means that the water incorporated in hydrolysis of glycosidic bonds is subtracted to obtain the same weight as the carbohydrate had in its polymerized form. In the expression 'as monosaccharide equivalents', mainly used in the British food composition tables (Food Standards Agency, 2002), the additional water remains part of the carbohydrate value. Therefore, if CHOAVLM is used, the sum of macronutrients in starchy foods often exceeds 100 g. For example, 100 g starch expressed in monosaccharide equivalent weights 110 g. On the other hand, when calculating carbohydrate values by difference, the sum of macronutrients always equals 100 g food weight. Even though, chemically, the grouping of carbohydrates is unambiguous, five definitions of carbohydrates are in use in food composition databases and labelling regulations leading to different values and thus inconsistencies and possible confusion.

Table 2
INFOODS TAGNAMES of the different carbohydrate definitions

INFOODS Tagname	Definition
Total carbohydrates	
CHOCDF	Carbohydrate, total (by difference): includes fibre. Calculated as: 100 g minus the sum of grams of water, protein, fat and ash
CHOCSM	Carbohydrate, total (by summation): includes fibre. Includes free sugars plus dextrin, oligosaccharides, starch, glycogen and dietary fibre
Available carbohydrates	
CHOAVL	Carbohydrate, available (by summation of analytical values), includes free sugars plus dextrin, starch and glycogen
CHOAVLDF	Carbohydrate, available (by difference). Calculated as: 100 g minus the sum of grams of water, protein, fat, fibre and ash
CHOAVLM	Carbohydrate, available, expressed as the monosaccharide equivalent, Includes free sugars plus dextrin, starch and glycogen

2.3. Dietary fibre

There are differences among experts in the physiological and chemical definitions of dietary fibre. Physiologically, dietary fibre is defined as 'the indigestible components of the plant cell wall' (Trowell, 1972) or 'the sum of the polysaccharides and lignin that are not digested by the endogenous secretions of the gastrointestinal tract' (Trowell et al., 1976).

In food composition databases and on labels, there are five major definitions of dietary fibre in use, which all depend on the analytical methods applied (Deharveng et al., 1999):

- TDF measured by the AOAC methods (based on the indigestibility of the components) is found in most food composition databases. They measure almost completely NSPs, lignin, and varying amounts of resistant starch and non-specific residues. The AOAC reference method is the enzymatic–gravimetric method of Prosky et al. (1985), and its modifications. The INFOODS Tagname is FIBTG.
- NSPs are measured by Englyst-type methods (Englyst et al., 1982; Englyst and Cummings, 1988) and are found in the British food composition tables. NSP values do not include lignin, waxes, cutins and resistant starch. The INFOODS Tagname is PSACNS.
- TDF by difference is calculated as following: 100−(water + protein + fat + ash + available carbohydrate). It includes resistant starch. This method is rarely used. The INFOODS Tagname is FIBCDF.
- The older Southgate-type methods (Southgate, 1969; Southgate et al., 1978; Wenlock et al., 1985) are currently rarely used, but can be found through the 5th edition of the British food composition tables (Holland et al., 1991b), and in the Greek Food Composition Table (1992). It is a colorimetric method measuring NSP, lignins and some starch. The INFOODS Tagname is FIBTS.
- Crude fibre, measured by the Weende method (AOAC, 1984), is the sum of plant substances resistant to hydrolysis by acids and subsequently by alkali. It captures part of lignin, cellulose and hemicellulose. Its values are substantially lower than for dietary fibre. Even though it is obsolete it is still used in food composition databases. The INFOODS Tagname is FIBC.

Because different components are captured in the five definitions for fibre, fibre values can be significantly different for the same foods and among food composition databases. New fibre definitions are being proposed (Slavin, 2003): 'functional fibre' (isolated, non-digestible carbohydrates that have beneficial physiological effects in human), 'dietary fibre' (intrinsic and intact) and 'total fibre' as the sum of both. The newly proposed term 'total fibre' could potentially cause confusion with the existing term 'TDF. Some reports discontinue the use of the terms soluble and insoluble fibre (FAO/WHO, 1998; Slavin, 2003). Several studies (Cummings, 1981; Roberfroid et al., 1993; Barry et al., 1995; Cummings et al., 1996; Castiglia-Delavaud et al., 1998; Wisker et al., 2000) show that part of the dietary fibre can be fermented in the colon by the micro-organisms and that the produced short chain fatty acids are absorbed. It is estimated that the metabolizable energy (ME) from these short chain fatty acids provide on average 8 kJ (2 kcal)/g dietary fibre (FAO, 2003).

2.4. Fat

There are three basic definitions of fat used in food composition databases and labelling regulations. Total fat, also called 'total lipid' or 'crude fat', is a mixture of triglycerides, phospholipids, wax esters, sterols and related compounds. It includes the weight of all lipid components soluble in the solvent system (Greenfield and Southgate, 2003). The energy values of crude fat can overestimate the energy available to the human body when phospholipids, wax esters, sterols and related compounds which contain fewer or no fatty acid moieties are present in high amounts. The US Nutrition Labelling and Education Act of 1990 (NLEA) (US FDA, 2002) expressed fat as triacylglycerol (triglyceride) equivalents determined as the sum of individual fatty acids. This NLEA fat value on food labels is often lower than 'total fat' values because it does not include phospholipids, sterols, wax esters and other related compounds. As a third definition, wax esters are subtracted from the 'total fat' values, at least for some foods such as pelagic fish (e.g., orange roughy), which has a high wax ester content (Crop & Food Research, 2003; USDA, 2003).

The result of the lipid analysis depends largely on extraction and hydrolysis. Different methods, which were developed for specific food matrices, now provide broadly similar values, as agreements on extraction and hydrolysis procedures have been reached (Greenfield and Southgate, 2003). Under these conditions, total fat values should be comparable among themselves and are potentially higher than the 'triglyceride equivalents' and 'total fat minus wax'. It seems however that the use of triacylglycerol equivalents of fatty acids is more precise, in terms of energy-providing potential, and is recommended (FAO, 2003).

2.5. Alcohol, polyols, organic acids

Alcohol is generally a measured and reported component for alcoholic beverages, with an assigned energy value. Few food composition databases list polyols or organic acids. By definition, they are included in the total carbohydrate by difference value, with no differentiation in the energy content. Where polyols and organic acids are reported on food labels or in food composition databases, they may appear as totals (e.g., total organic acids) with a common energy value according to the EU Directive (EU Council Directive 90, 496 and EEE of 24 September, 1990) or as individual components (e.g., citric acid, acetic acid) with individual energy factors (Australian New Zealand Food Standard Code, 2003).

2.6. Food energy

There are different concepts to define energy in foods: it can be described as the heat produced by the food (= gross energy—GE), as the energy available for body functions (= ME) or as the adenosine-triphosphate (ATP) available to the human body. Each leads to different energy conversion factors (see Materials and Methods section).

GE of foods is analysed through bomb calorimeter (Miller and Payne, 1959) and represents the heat production of foods and nutrients when completely oxidized to carbon dioxide and water (FAO, 2003). GE does not take into account losses in the human body due to faeces, urine, skin and gases, and therefore does not reflect the energy that the food provides to the human body. However, if foods are analysed for GE the definitions of macronutrients are irrelevant. GE is not commonly encountered in food composition databases or in labelling legislation, because it is not comparable to energy requirements. Energy requirements are based on the concept of metabolizable food energy (ME), i.e., the energy available to the human body for maintenance, physical activity, pregnancy, lactation and growth (WHO, 1985). The ME values are based on energy conversion factors, either the general Atwater factors or the food specific factors of Merrill & Watt also called specific Atwater factors (Merrill and Watt, 1973). These sets of conversion factors are attributed to values of energy-providing nutrients, which include carbohydrate, protein, fat, fibre, alcohol, polyols, and organic acids. It is obvious that the nutrient definitions with their varying values are relevant in the calculation of ME. For example, for total carbohydrate, the general Atwater factor is 17 kJ/g (4 kcal/g). For available carbohydrate expressed in monosaccharides, through the so-called Southgate and Durnin (1970) factor, it is 16 kJ/g (3.75 kcal/g). It should be stressed that general and specific Atwater factors are meant to be applied to total carbohydrate by difference but not to available carbohydrate. Recently, the concept of Net Metabolizable Energy (NME) has been debated (FAO, 2003). NME aims to take ME one step further by accounting for heat lost through fermentation and obligatory thermogenesis.

3. Part II: impact of selected nutrient definitions on energy supply

3.1. Materials and methods

The food supply data of the FAO Statistical Databases (FAOSTAT, 2003) of 1999–2001 were used representing 506 food commodities and aggregations. Food supply represents the food available for human consumption. The food supply values were adjusted for non-edible parts. In the following, the food supply data used in the different countries will be called 'diet'. Nine countries (Afghanistan, Bangladesh, Guatemala, Guinea, Iran, Italy, Mozambique, Tunisia, and USA) were chosen because they represent a variety of diets from different regions. Afghanistan, Bangladesh and Iran are characterized by a high-energy contribution from rice and/or wheat. Maize and/or tubers are important in Guatemala, Guinea and Mozambique, in the latter also sorghum. A mixed diet is observed in Italy, Tunisia and the USA (see Table 3). The FAOSTAT (2003) foods were matched to the closest foods from the USDA (2003) and the British food composition tables (Holland et al., 1988, 1989, 1991a, b, 1993; Chan et al., 1994, 1995, 1996; Food Standards Agency, 2002).

Most of the nutrient values are from USDA (2003) Standard Release 15 (total carbohydrate by difference, protein based on Jones factors, fat, AOAC dietary fibre). Available carbohydrate as monosaccharide equivalents and NSP dietary fibre are taken from the 6th edition and other supplements of the British food composition tables (Holland et al., 1988, 1989, 1991, b, 1993; Chan et al., 1994, 1995, 1996; Food Standards Agency, 2002). Based on the USDA values, some nutrient values were calculated such as 'available carbohydrate by difference', total nitrogen (N), protein as N × 6.25 and as the sum of amino acids. Missing values were estimated.

Per capita energy supply values were calculated using the energy conversion factors (see Table 4) for GE values, general and specific Atwater factors. Specific Atwater factors are listed in Table 5. Using available carbohydrate, the energy supply was calculated with and without an

Table 3
Energy supply contribution in % from main food staples and groups in nine countries

Staple foods	Wheat (%)	Rice (%)	Maize (%)	Millet and sorghum (%)	Roots and tubers (%)	Animal prod. (%)	Others (%)	Total energy supply[a] (kJ (kcal)/capita/day)
Afghanistan	56	9	2	0.5	1	17	14	7090 (1695)
Iran	46	11	0.5	0	3	9	31	12589 (3009)
Bangladesh	8	75	0	0	1	3	13	9044 (2162)
Guinea	4	33	4	0.5	14	3	42	9458 (2261)
Mozambique	4	5	23	8	37	3	21	8390 (2005)
Guatemala	12	1	43	0.5	0.5	9	34	9147 (2186)
Tunisia	51	0.5	0	0	2	9	38	14441 (3451)
Italy	29	2	1	0	2	26	40	15497 (3704)
USA	17	2	3	0.5	3	27	47	16165 (3864)

[a] Calculated with specific Atwater and Jones factors.

Table 4
Energy conversion factors in kJ (kcal)/g

	Protein	Carbohydrates	Fat	Alcohol	Dietary fibre
Gross energy	24 (5.65)	17 (4)	40 (9.4)	30 (7)	17 (4)
General Atwater	17 (4)	−17 (4) −16 (3.75) for carbohydrates as monosaccharide equivalent	37 (9)	29 (7)	−0 (0) −8 (2) as newly recommended
Specific Atwater (Merrill & Watt)[a]	10.2 (2.44) to 18.2 (4.36)	5.56 (1.33) to 17.24 (4.12)	35 (8.37) to 37.7 (9.02)	29 (7)	(part of total carbohydrates by difference)

[a] See Table 5 for individual food factors.

energy value of 8 kJ/g (2 kcal/g) for dietary fibre as recently recommended (FAO/WHO, 1998). The energy contribution of organic acids and polyols was not calculated therefore no energy conversion factors are mentioned for these components.

3.2. Combinations of macronutrient definition

There are 975 theoretical combinations of macronutrient definitions (see Table 6). For this paper, we retained three definitions for carbohydrate (total, available by difference, available as monosaccharide equivalents), three protein definitions (N × Jones factors and N × 6.25 assuming total nitrogen as basis, and sum of amino acids), one for fat (total lipid), and two for dietary fibre (AOAC, NSP). This resulted in 15 combinations of nutrient definitions since NSP fibre was only applied to available carbohydrate expressed as monosaccharide equivalents.

4. Results

4.1. Impact of energy conversion factors on energy supply values

The energy supply ranged from 7090 to 16165 kJ/capita/day (1695–3864 kcal/capita/day). As shown in Tables 7 and 8 the GE values for protein, fat and fibre are higher than the general or specific Atwater factors which explains the 290–1500 kJ/capita/day (70–360 kcal/capita/day) higher energy supply based on GE and the same nutrient definitions.

Within the ME, the specific Atwater factors resulted in higher values only in the high rice consuming countries such as Bangladesh and Afghanistan (50 and 70 kJ/capita/day), whereas for the other diets the general Atwater factors resulted in higher energy supply (65–320 kJ/capita/day). The relative amounts of individual foods in the diet dictate whether general or specific Atwater factors generate higher values. Specific Atwater factors are lower for plant-based foods than for animal-based foods, except for white rice and wheat for which the specific carbohydrate energy values are 4.16 and 4.12 kcal/g, respectively. This difference of 0.12 or 0.16 kcal/g may have a major impact on energy supply in countries where these specific foods are highly consumed, e.g., rice in Bangladesh.

Table 5
Atwater specific factors for selected foods

	Protein kcal/g (kJ/g)	Fat kcal/g (kJ/g)	Carbohydrate kcal/g (kJ/g)
Eggs, meat products, milk products			
Eggs	4.36 (18.2)	9.02 (37.7)	3.68 (15.4)
Meat/fish	4.27 (17.9)	9.02 (37.7)	[a]
Milk/milk products	4.27 (17.9)	8.79 (36.8)	3.87 (16.2)
Fats—separated			
Butter	4.27 (17.9)	8.79 (36.8)	3.87 (16.2)
Margarine, vegetable	4.27 (17.9)	8.84 (37.0)	3.87 (16.2)
Other vegetable fats and oils	—	8.84 (37.0)	—
Fruits			
All, except lemons, limes	3.36 (14.1)	8.37 (35.0)	3.60 (15.1)
Fruit juice, except lemon, lime[b]	3.36 (14.1)	8.37 (35.0)	3.92 (15.1)
Lemons, limes	3.36 (14.1)	8.37 (35.0)	2.48 (10.4)
Lemon juice, lime juice[b]	3.36 (14.1)	8.37 (35.0)	2.70 (11.3)
Grain products			
Barley, pearled	3.55 (14.9)	8.37 (35.0)	3.95 (16.5)
Cornmeal, whole ground	2.73 (11.4)	8.37 (35.0)	4.03 (16.9)
Macaroni, spaghetti	3.91 (16.4)	8.37 (35.0)	4.12 (17.2)
Oatmeal—rolled oats	3.46 (14.5)	8.37 (35.0)	4.12 (17.2)
Rice, brown	3.41 (14.3)	8.37 (35.0)	4.12 (17.2)
Rice, white or polished	3.82 (16.0)	8.37 (35.0)	4.16 (17.4)
Rye flour—whole grain	3.05 (12.8)	8.37 (35.0)	3.86 (16.2)
Rye flour—light	3.41 (14.3)	8.37 (35.0)	4.07 (17.0)
Sorghum—whole meal	0.91 (3.8)	8.37 (35.0)	4.03 (16.9)
Wheat—97–100% extraction	3.59 (14.0)	8.37 (35.0)	3.78 (15.8)
Wheat—70–74% extraction	4.05 (17.0)	8.37 (35.0)	4.12 (17.2)
Other cereals—refined	3.87 (16.2)	8.37 (35.0)	4.12 (17.2)
Legumes, nuts			
Mature dry beans, peas, nuts	3.47 (14.5)	8.37 (35.0)	4.07 (17.0)
Soybeans	3.47 (14.5)	8.37 (35.0)	4.07 (17.0)
Vegetables			
Potatoes, starchy roots	2.78 (11.6)	8.37 (35.0)	4.03 (16.9)
Other underground crops	2.78 (11.6)	8.37 (35.0)	3.84 (16.1)
Other vegetables	2.44 (10.2)	8.37 (35.0)	3.57 (14.9)

Original data were published in kcal/g; values for kJ/g have been calculated from calorie values.
Source: Modified from Merrill and Watt (1973) as published in FAO (2003).

[a] Carbohydrate factor is 3.87 for brain, heart, kidney, liver; 4.11 for tongue and shellfish.

[b] Unsweetened.

Table 6
Possible number of nutrient definitions and their combination

	Protein	Fat	Carbohydrates	Fibre	Alcohol	Polyols	Organic acids	Total
Number of theoretical definitions	13	3	5	5	1	1	1	975

4.2. Impact of protein definitions on protein and energy supply

As shown in Table 9, protein supply varied from 35 to 121 g/capita/day (7–11% energy from protein). For the same diet, the variation was 1–7 g/capita/day depending on the protein definition. Protein supply calculated as N × 6.25 resulted in the highest values, followed by N × Jones factors and the sum of amino acids. One reason for the lower values for the sum of amino acids might be that the complete amino acid profile has not been analysed for every food in the USDA database. If carbohydrate by difference is used with general Atwater factors, the energy supply remains the same for all protein definitions because the energy conversion factors of protein and carbohydrate is 17 kJ/g. The three protein calculation methods changed the energy supply by 4–100 kJ (1–25 kcal) or $<1\%$ difference in energy supply (see Tables 7 and 8).

4.3. Impact of carbohydrate and dietary fibre definitions on nutrient and energy supply

The carbohydrate supply ranged from 295 to 540 g/capita/day (50–80% of energy from total carbohydrate), depending on the nutrient definition and the diet (see Table 10). The carbohydrate supply from available carbohydrate expressed as monosaccharide (CHOAVLM) was close to the total carbohydrate (CHOCDF) supply, and the lowest supply was found with the use of available carbohydrate by difference (CHOAVDF). The difference in the carbohydrate supply between total and available carbohydrate by difference was the fibre supply. By definition, this difference increases as the amount of fibre-rich foods in the diet increases. In the diets examined, the fibre supply ranged for AOAC TDF from 13 to 32 g/capita/day and for NSP between 7 and 30 g/capita/day.

The greatest differences within the general Atwater system were between available carbohydrate expressed as monosaccharide equivalents without energy value for fibre and total carbohydrate by difference. This accounted for differences in the energy supply of 3.5–8% or 330–780 kJ/capita/day (80–190 kcal/capita/day). It can be explained by the fact that the value of the carbohydrate supply is similar in most examined diets, if based on total carbohydrate or on available carbohydrate as monosaccharide equivalents (Table 10) but there is 1 kJ difference in the energy conversion factor (total carbohydrate 17 kJ/g and carbohydrate as monosaccharide 16 kJ/g). Differences in energy supply between total and available carbohydrate by difference in the general Atwater system were due to the inclusion of fibre in total carbohydrate, which gave fibre an energy value of 17 kJ/g. Using AOAC dietary fibre supply in the nine diets (12.7–32 g) leads to a difference in energy supply of 220–540 kJ/capita/day and using NSP (6.9–29.9 g) of 120–510 kJ/day. This means that the divergence in energy supply between total and available carbohydrate by difference increases with increasing fibre content of the diet and is greater when using AOAC TDF. Differences in the food carbohydrate values or of energy conversion factors for

Table 7
Energy supply in kcal/capita/day of FAOSTAT 1999–2001 based on nutrient values from USDA SR15 and the British tables[a]

Equation	Afghanistan			Mozambique			Bangladesh			Guatemala		
	GE	MW	Atwater	GE	MW	Atwater	GE	MW	Atwater	GE	MW	Atwater
CHOCDF, Jones	1772	1695	1677	2122	2005	2045	2236	2162	2149	2356	2186	2252
CHOAVLDF, Jones, AOAC fibre energy	1772	NA	1647	2122	NA	1995	2236	NA	2124	2356	NA	2195
CHOAVLDF, Jones, no fibre energy	1711	NA	1617	2022	NA	1946	2185	NA	2099	2244	NA	2139
CHOAVLM, Jones, AOAC fibre energy	1751	NA	1626	2088	NA	1962	2186	NA	2073	2299	NA	2138
CHOAVLM, Jones, NSP fibre energy	1748	NA	1624	2081	NA	1958	2162	NA	2062	2297	NA	2137
CHOAVLM, Jones, no fibre energy	1690	NA	1596	1989	NA	1912	2135	NA	2048	2186	NA	2081
CHOCDF, N × 6.25	1774	1693	1675	2100	1991	2029	2237	2159	2147	2361	2191	2256
CHOAVLDF, N × 6.25, AOAC fibre energy	1773	NA	1645	2088	NA	1967	2242	NA	2127	2340	NA	2179
CHOAVLDF, N × 6.25, no fibre energy	1713	NA	1614	1988	NA	1917	2191	NA	2102	2227	NA	2122
CHOAVLM, N × 6.25, AOAC fibre energy	1764	NA	1635	2068	NA	1948	2194	NA	2080	2299	NA	2138
CHOAVLM, N × 6.25, NSP fibre energy	1761	NA	1633	2061	NA	1944	2171	NA	2068	2297	NA	2137
CHOAVLM, N × 6.25, no fibre energy	1703	NA	1605	1969	NA	1898	2144	NA	2054	2186	NA	2081
CHOCDF, sum AA	1771	1695	1678	2117	2009	2045	2235	2162	2150	2363	2195	2261
CHOAVLDF, sum AA, AOAC fibre energy	1770	NA	1647	2104	NA	1982	2235	NA	2124	2341	NA	2183
CHOAVLDF, sum AA, no fibre energy	1709	NA	1617	2004	NA	1932	2184	NA	2099	2229	NA	2126
CHOAVLM, sum AA, AOAC fibre energy	1745	NA	1622	2072	NA	1950	2180	NA	2070	2291	NA	2132
CHOAVLM, sum AA, NSP fibre energy	1742	NA	1620	2064	NA	1946	2157	NA	2058	2289	NA	2131
CHOAVLM, sum AA, no fibre energy	1684	NA	1591	1972	NA	1900	2129	NA	2044	2178	NA	2075

	Guinea			Iran			Tunisia			Italy			USA		
Equation	GE	MW	Atwater	GE	MW	Atwater	GE	MW	Atwater	GE	MW	Atwater	GE	MW	Atwater
CHOCDF, Jones	2441	2261	2337	3176	3009	3024	3668	3451	3477	4020	3704	3762	4183	3864	3926
CHOAVLDF, Jones, AOAC fibre energy	2441	NA	2276	3176	NA	2965	3668	NA	3413	4020	NA	3705	4183	NA	3878
CHOAVLDF, Jones, no fibre energy	2319	NA	2215	3058	NA	2907	3540	NA	3349	3906	NA	3647	4087	NA	3830
CHOAVLM, Jones, AOAC fibre energy	2484	NA	2320	3126	NA	2916	3624	NA	3369	3946	NA	3630	4119	NA	3814
CHOAVLM, Jones, NSP fibre energy	2476	NA	2315	3107	NA	2906	3608	NA	3360	3930	NA	3622	4098	NA	3804
CHOAVLM, Jones, no fibre energy	2362	NA	2259	3009	NA	2857	3496	NA	3305	3832	NA	3573	4023	NA	3766
CHOCDF, N × 6.25	2433	2255	2331	3182	3008	3023	3678	3454	3480	4041	3719	3777	4200	3877	3940
CHOAVLDF, N × 6.25, AOAC fibre energy	2431	NA	2268	3182	NA	2965	3678	NA	3416	4040	NA	3720	4199	NA	3890
CHOAVLDF, N × 6.25, no fibre energy	2309	NA	2207	3065	NA	2906	3550	NA	3352	3926	NA	3662	4103	NA	3843
CHOAVLM, N × 6.25, AOAC fibre energy	2477	NA	2314	3149	NA	2932	3647	NA	3385	3962	NA	3642	4130	NA	3822
CHOAVLM, N × 6.25, NSP fibre energy	2468	NA	2310	3130	NA	2923	3631	NA	3377	3946	NA	3634	4109	NA	3812
CHOAVLM, N × 6.25, no fibre energy	2355	NA	2254	3032	NA	2873	3519	NA	3321	3848	NA	3585	4034	NA	3774
CHOCDF, sum AA	2442	2268	2342	3173	3011	3026	3673	3461	3486	4043	3729	3786	4199	3884	3945
CHOAVLDF, sum AA, AOAC fibre energy	2439	NA	2278	3172	NA	2967	3674	NA	3422	4042	NA	3728	4197	NA	3895
CHOAVLDF, sum AA, no fibre energy	2317	NA	2217	3055	NA	2908	3546	NA	3358	3928	NA	3671	4101	NA	3847
CHOAVLM, sum AA, AOAC fibre energy	2470	NA	2310	3110	NA	2904	3611	NA	3359	3939	NA	3626	4110	NA	3808
CHOAVLM, sum AA, NSP fibre energy	2462	NA	2306	3091	NA	2895	3594	NA	3351	3923	NA	3618	4089	NA	3797
CHOAVLM, sum AA, no fibre energy	2348	NA	2249	2993	NA	2846	3483	NA	3295	3825	NA	3569	4014	NA	3760

NA = non applicable, GE = gross energy, MW = Merrill & Watt or specific Atwater factors, Atwater = general Atwater factors.

[a] Holland et al. (1988, 1989, 1991a, b, 1993); Chan et al. (1994, 1995, 1996); Food Standards Agency (2002).

Table 8
Energy supply in kJ/capita/day of FAOSTAT 1999–2001 based on nutrient values from USDA SR15 and the British tables[a]

Equation in kJ	Afghanistan			Mozambique			Bangladesh			Guatemala		
	GE	MW	Atwater	GE	MW	Atwater	GE	MW	Atwater	GE	MW	Atwater
CHOCDF, Jones	7414	7090	7017	8878	8390	8557	9356	9044	8993	9859	9147	9421
CHOAVLDF, Jones, AOAC fibre energy	7414	NA	6891	8878	NA	8349	9356	NA	8887	9859	NA	9185
CHOAVLDF, Jones, no fibre energy	7161	NA	6765	8461	NA	8140	9144	NA	8781	9387	NA	8949
CHOAVLM, Jones, AOAC fibre energy	7325	NA	6802	8738	NA	8209	9144	NA	8675	9619	NA	8944
CHOAVLM, Jones, NSP fibre energy	7313	NA	6796	8706	NA	8193	9047	NA	8627	9612	NA	8941
CHOAVLM, Jones, no fibre energy	7072	NA	6676	8321	NA	8000	8932	NA	8569	9147	NA	8708
CHOCDF, N × 6.25	7421	7082	7009	8786	8330	8490	9358	9034	8984	9878	9167	9440
CHOAVLDF, N × 6.25, AOAC fibre energy	7419	NA	6881	8735	NA	8230	9379	NA	8900	9789	NA	9115
CHOAVLDF, N × 6.25, no fibre energy	7166	NA	6755	8318	NA	8022	9168	NA	8794	9317	NA	8879
CHOAVLM, N × 6.25, AOAC fibre energy	7378	NA	6840	8654	NA	8150	9180	NA	8701	9617	NA	8943
CHOAVLM, N × 6.25, NSP fibre energy	7367	NA	6834	8623	NA	8134	9083	NA	8652	9611	NA	8940
CHOAVLM, N × 6.25, no fibre energy	7126	NA	6714	8238	NA	7941	8968	NA	8595	9145	NA	8707
CHOCDF, sum AA	7410	7094	7021	8857	8404	8557	9352	9047	8996	9886	9183	9458
CHOAVLDF, sum AA, AOAC fibre energy	7405	NA	6890	8802	NA	8293	9349	NA	8887	9797	NA	9133
CHOAVLDF, sum AA, no fibre energy	7152	NA	6764	8386	NA	8085	9137	NA	8781	9325	NA	8896
CHOAVLM, sum AA, AOAC fibre energy	7300	NA	6785	8668	NA	8159	9121	NA	8659	9584	NA	8920
CHOAVLM, sum AA, NSP fibre energy	7288	NA	6779	8637	NA	8144	9025	NA	8611	9577	NA	8916
CHOAVLM, sum AA, no fibre energy	7047	NA	6659	8252	NA	7951	8910	NA	8553	9112	NA	8684

Equation	Guinea			Iran			Tunisia			Italy			USA		
	GE	MW	Atwater	GE	MW	Atwater	GE	MW	Atwater	GE	MW	Atwater	GE	MW	Atwater
CHOCDF, Jones	10212	9458	9780	13287	12589	12652	15347	14441	14547	16821	15497	15739	17501	16165	16426
CHOAVLDF, Jones, AOAC fibre energy	10212	NA	9525	13287	NA	12407	15347	NA	14279	16821	NA	15500	17501	NA	16226
CHOAVLDF, Jones, no fibre energy	9702	NA	9269	12796	NA	12162	14811	NA	14011	16343	NA	15261	17101	NA	16025
CHOAVLM, Jones, AOAC fibre energy	10393	NA	9705	13080	NA	12200	15163	NA	14095	16510	NA	15189	17234	NA	15958
CHOAVLM, Jones, NSP fibre energy	10358	NA	9687	13000	NA	12160	15094	NA	14060	16441	NA	15155	17147	NA	15915
CHOAVLM, Jones, no fibre energy	9883	NA	9450	12589	NA	11954	14627	NA	13827	16032	NA	14950	16833	NA	15757
CHOCDF, N × 6.25	10179	9436	9755	13312	12584	12650	15388	14451	14560	16906	15560	15804	17575	16222	16486
CHOAVLDF, N × 6.25, AOAC fibre energy	10170	NA	9490	13313	NA	12405	15389	NA	14292	16903	NA	15563	17567	NA	16278
CHOAVLDF, N × 6.25, no fibre energy	9659	NA	9235	12823	NA	12160	14852	NA	14024	16425	NA	15324	17166	NA	16077
CHOAVLM, N × 6.25, AOAC fibre energy	10363	NA	9684	13176	NA	12268	15261	NA	14164	16578	NA	15238	17280	NA	15991
CHOAVLM, N × 6.25, NSP fibre energy	10328	NA	9666	13097	NA	12228	15191	NA	14129	16509	NA	15203	17194	NA	15947
CHOAVLM, N × 6.25, no fibre energy	9853	NA	9429	12685	NA	12022	14724	NA	13896	16100	NA	14998	16879	NA	15790
CHOCDF, sum AA	10217	9488	9801	13275	12597	12660	15367	14480	14583	16915	15602	15842	17570	16249	16506
CHOAVLDF, sum AA, AOAC fibre energy	10204	NA	9532	13273	NA	12413	15371	NA	14319	16912	NA	15600	17561	NA	16296
CHOAVLDF, sum AA, no fibre energy	9693	NA	9277	12783	NA	12168	14835	NA	14051	16434	NA	15360	17160	NA	16096
CHOAVLM, sum AA, AOAC fibre energy	10335	NA	9664	13011	NA	12151	15107	NA	14055	16483	NA	15170	17196	NA	15931
CHOAVLM, sum AA, NSP fibre energy	10300	NA	9647	12932	NA	12112	15038	NA	14021	16414	NA	15136	17109	NA	15888
CHOAVLM, sum AA, no fibre energy	9825	NA	9409	12521	NA	11906	14571	NA	13787	16004	NA	14931	16795	NA	15731

NA = non applicable, GE = gross energy, MW = Merrill & Watt or specific Atwater factors, Atwater = general Atwater factors.

[a] Holland et al. (1988, 1989, 1991a, b, 1993); Chan et al. (1994, 1995, 1996); McCance and Widdowson's (2002).

Table 9
Protein supply in g/capita/day for three definitions (N × Jones factor, N × 6.25, sum of amino acids) of nine countries using FAOSTAT food supply data for 3-years average of 1999–2001

Country	Protein		
	(N × Jones)	(N × 6.25)	(sum AA)
Afghanistan	49	52	48
Bangladesh	46	48	45
Guatemala	52	52	51
Guinea	48	46	45
Iran	77	81	74
Italy	119	122	118
Mozambique	38	35	35
Tunisia	90	94	88
USA	118	120	117

Table 10
Carbohydrate and dietary fibre supply in g/capita/day of nine countries using FAOSTAT food supply data for 3-year-average of 1999–2001

Country	Total carbohydrates by difference (CHOCDF)	Available carbohydrates as monosaccharides (CHOAVLM)	Available carbohydrates by difference (CHOAVLDF)	Total dietary fibre	NSP fibre
Afghanistan	294	292	279	15	14
Bangladesh	433	435	420	13	7
Guatemala	400	382	372	28	28
Guinea	396	401	366	31	28
Iran	540	531	510	29	25
Italy	442	421	413	29	25
Mozambique	394	385	369	25	23
Tunisia	537	526	505	32	28
USA	487	477	463	24	19

carbohydrates had a great impact on carbohydrate and energy supply because of the high carbohydrate content in most diets.

Differences in energy supply between total and available carbohydrate, and differences between general and specific Atwater factors, could be minimized by applying an energy factor of 8 kJ/g (2 kcal/g) for AOAC dietary fibre (Fig. 1). This could lead to an increase of 100–250 kJ/capita/day (25–60 kcal/capita/day) or 1–2% in energy supply (see Fig. 1 and Tables 7 and 8). If NSP dietary fibre would be used, the increase in energy supply would be 5–50 kJ/capita/day (1–12 kcal/capita/day) lower than for AOAC TDF because NSP dietary fibre results in 1–6 g/capita/day lower fibre supply (1–45%) than the TDF in the diets of the nine countries studied. On average, in these diets NSP values were 16% lower than those of TDF. Excluding the high rice consuming countries, the

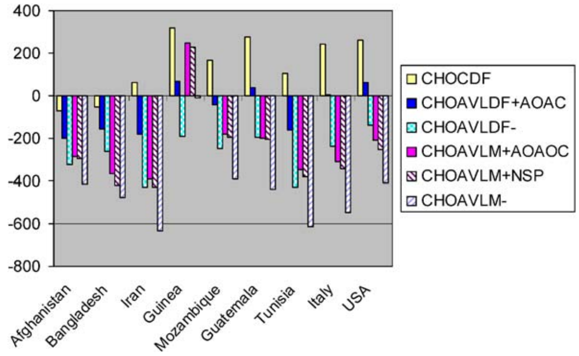

Fig. 1. Differences in kJ/capita/day between energy supply calculated with total carbohydrates and specific Atwater factors (=zero line) and energy supply calculated with general Atwater and different carbohydrate and dietary fibre definitions, with/without energy for fibre. CHOCDF = total carbohydrates by difference; CHOAVLDF + AOAC = available carbohydrates by difference with energy for AOAC dietary fibre; CHOAVLDF = available carbohydrates by difference without energy for dietary fibre; CHOAVLM + AOAC = available carbohydrates expressed as monosaccharide equivalents with energy for AOAC dietary fibre; CHOAVLM + NSP = available carbohydrates expressed as monosaccharide equivalents with energy for NSP dietary fibre; CHOAVLM = available carbohydrates expressed as monosaccharide equivalents without energy for dietary fibre.

average difference between the two fibre definitions dropped to 8.5%. This is mainly due to the NSP fibre value for raw white rice of 0.5 g/100g compared to 1.3 g/100g for TDF. This shows that attributing an energy value to dietary fibre has a significant impact on energy supply but that the fibre definition has only a small impact on energy supply.

5. Discussion and conclusion

As shown in this article, nutrient definitions are important considerations for the energy values of foods. Because nutrient definitions are tied to the nutrient and energy values, there is a need to reach international agreement on macronutrient definitions. This agreement should be reached in and applied to all appropriate areas such as food composition database programs, data interchanges, and food labelling. However, such an agreement is difficult to reach as nutrient definitions and energy factors are firmly anchored by tradition or regulations in the different applications at national and international level. Nevertheless, international organizations such as WHO and FAO and other groups are increasingly collaborating in developing sound and universally usable standards. Recently, a FAO technical workshop (2003) made recommendations, based on current knowledge, on preferred and accepted macronutrient definitions and energy conversion factors which, if applied globally, could contribute to the international harmonization and comparability of nutrient and energy values. It would also be helpful to identify the food components uniformly and precisely, i.e., to capture differences in nutrient definitions. One possible solution would be to use the INFOODS TAGNAMES (Klensin et al., 1989), which are currently being updated and revised. An interim or compromise solution to standardization is found in the Philippine food composition database where crude fibre values are being phased out (Food and Nutrition Research Institute, 1997); AOAC dietary fibre is used as default and crude fibre values are listed in brackets.

Protein, with the three different definitions examined, did influence the protein and energy supply values only to a small extent. If however, total nitrogen would be multiplied with the newly proposed nitrogen conversion factor of 5.7 or 5.33 the protein supply would drop by 9% or 15%, respectively, compared to the use of the nitrogen conversion factor 6.25. The energy supply for all three definitions remains almost the same if calculated with general Atwater factors and carbohydrate by difference. For the other definitions, a drop in energy supply would be observed as the values of the other nutrients would not be adjusted accordingly.

Carbohydrate and fibre values and supplies are heavily influenced by their definitions. Therefore, if agreement on carbohydrate and fibre definitions could be found, a big step forward in international harmonization and comparability of values could be achieved. Based on current knowledge, available carbohydrate by weight together with AOAC TDF with an energy value of 8 kJ/g were considered preferable (FAO, 2003). In food composition databases and for food labelling, available carbohydrate and AOAC fibre are becoming more frequently used, and energy factors for fibre are appearing in food labelling regulations (Australian New Zealand Food Standard Code, 2003; Malaysian nutrition labelling regulation 18B, 2003). NSP and available carbohydrate expressed as monosaccharide equivalents are mainly used in Britain since the 6th edition of the British food composition tables (Food Standards Agency, 2002), Southgate fibre was removed and AOAC TDF values were presented in an annex. Most experts consider that crude fibre is obsolete for human nutrition purposes (FAO, 2003) and labelling regulations and food databases are substituting other fibre methods. Despite the repeated recommendation over the last 20 years that total carbohydrate by difference not be used in food composition (FAO/WHO, 1980, 1998; Greenfield and Southgate, 2003), it is still present in many recent food composition databases, e.g., USDA SR16 (2004), the Danish Food Composition Table (1996), Greek Food Composition Table (1992), ASEAN Food Composition Tables (2000), and Composition of South African Foods—Vegetables and Fruits (1998). Available carbohydrate by difference is used in the Swedish Food Composition Database (2002) and is permitted in the Australian New Zealand Food Standard Code (2003). The calculation of total or available carbohydrate by difference is more convenient and cost effective, but has the disadvantage of incorporating all the measurement errors of the analysis of the other macronutrients and not allowing differentiation of the individual carbohydrate constituents. Additionally, for the value of available carbohydrate by difference, the choice of the dietary fibre definition becomes important as shown.

Both the specific and general Atwater factors were experimentally determined with application to total carbohydrate by difference (Merrill and Watt, 1973). Specific Atwater factors are only applied to total carbohydrate by difference, as is done in the USDA database. In practice, general Atwater factors are applied to available as well as total carbohydrate values, without taking the difference in the carbohydrate definitions into account. The energy conversion factor of 16 kJ/g, the energy value of glucose (Southgate and Durnin, 1970), is only applied to available carbohydrate expressed in monosaccharide equivalents, to account for the higher weight due to the hydrated glucose molecule. Differences of up to 780 kJ/capita/day in energy supply were observed, as shown in Fig. 1, between total and available carbohydrate in the general Atwater system without attributing an energy value to dietary fibre. This means that for the same diets up to 8% difference in energy supply can be calculated. In many developing countries, total carbohydrate and general Atwater factors are used. Except for the high cereal consuming countries, a shift to available carbohydrate would mean a significant decrease in energy supply, which consequently would increase the percentage of the population not meeting their energy requirement.

These differences in macronutrients and energy supply are also applicable to intake data and differences are expected to be in the same range. Therefore, comparison and use of these data across countries might lead to different interpretations. For example, for the same diet, the energy and macronutrient intake estimates will vary depending on the nutrient definition and energy factors used. Therefore, the percentage of the population reaching energy adequacy, the % of energy from macronutrients, the ranking of subjects according to intake, energy adjusted intakes or other factors, and the possible use of dietary data from different countries in meta-analysis, may be questioned.

More research is needed on the impact of macronutrient definitions on nutrient and energy intake, comparisons among countries, impact on research results, comparisons with energy requirements or energy expenditure, nitrogen conversion factors, and a comprehensive review of energy conversion factors involving both metabolic and analytical chemistry aspects of macronutrients.

The international community should agree on a harmonized terminology system for nutrient definitions and corresponding energy conversion factors. Agreement on the discontinuation of total carbohydrate would render specific Atwater factors obsolete thus eliminating the biggest difference in carbohydrate and energy values, as shown in this paper. This would leave the agreement to be taken on available carbohydrate and dietary fibre definitions which have less influence on the energy supply. Available carbohydrate as monosaccharide equivalents is rarely used which would mainly leave the choice between 'by weight' and 'by difference'. The debate on fibre definitions has a long history of disagreement. Nevertheless, with crude and Southgate fibre being phased out, and fibre by difference acknowledged as a poor choice, the decision could focus on NSP and TDF (AOAC, 2003).

Once agreement is reached, the definitions and factors could then be adopted globally in the same way and in all applications, including food composition databases and labelling regulations at national and international levels, e.g., US FDA (2002), Codex Alimentarius (2001), and EU labelling regulations (EU Council, 1990). With standardization in place, research results on diet-related disease risk as well as nutrient and energy intake estimations will be more comparable across countries, and dietary guidelines and goals, as well as nutrition programs, will have the same basis all over the world.

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