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Measurement and Evaluation of Carbon Emission for Different Types of Carbohydrate-rich Foods in China

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The food system significantly contributes to global carbon emissions, which has attracted attention of researchers. Carbohydrate-rich (CR) foods as very important components of Chinese traditional foods, are the most important energy sources for human body. In this study, carbon emissions of twenty types of CR foods including grains, beans, and tubers food during cultivation, processing, and transportation phase were investigated according to the LCA principle. The present research showed that different food types showed significantly various environmental influences. The carbon emissions produced by the foods were evaluated based on different function units (mass, food-supplying energy and nutritional values based on specific nutrition profiling models). The rankings of foods according to carbon emission per unit mass were similar to those using the energy as function unit. However, when nutrition values based on specific five or twenty-one nutrient contents were used as the function unit, the rankings varied. It implied that comprehensive evaluation of food function was important for more accurately illustrating the impacts of consumption choice to different CR foods on the environment. In summary, the results revealed that consumption of more wheatberry and standard wheat flour could be a feasible plan to reduce carbon emissions in Chinese society in nowadays. Meanwhile, the increase in consumption of corn kernels, sweet potato, and potato instead of rice-based foods or tailored flour (grade one) could cut a considerable amount of carbon emissions further in future.

1. Introduction

Global warming is a worldwide issue with its evident impacts across a wide range of systems and sectors. Global warming is caused by greenhouse gas (GHG) emissions, to which food systems contribute a large part (Xu et al., 2015). Great attention of many researchers has been attracted to reduce GHG emissions in food systems. The global warming potential of different food sectors is diverse (Nemecek et al., 2012). What a person chooses to eat makes a different environmental impact (Pairotti et al, 2015). Currently, one goal of many studies in food systems is to identify the most polluting food items or to compare dietary choices (Berners-Lee et al., 2012). CR foods including grains, beans, and tubers, are the most important energy source for Chinese people. In China, the amount of grain consumption is huge, and was 134.5 kg/ person y in 2015 (NBS, 2016). It is of great importance to study the carbon emissions of different types of CR foods. The carbon emissions of many types of cereal products were estimated. A national average GHG intensity of rice, wheat, and maize production in China was 0.947, 0.265, and 0.230 kgCO_2eq/kg, (Wang et al., 2015). Many studies on product CF (carbon footprint) in food systems were usually compared based on mass or volume. Although mass or volume as the basic quantities are the most often used for many quantification, it ignores however an important function of food products – nutrition sources. Nutrient content of foods could reflect the function of foods better in comparison with mass or volume. Nutrient content of foods could be represented by the amount of carbohydrate, fat, protein, fibre, vitamins, minerals, etc. Protein efficiency was quite often used as an effective functional unit during evaluation of carbon emission of protein-rich foods (Flysjö et al., 2012). If a food product A is lack of carbohydrate but rich in protein, and another food product B is rich in carbohydrate but lack of protein, it is unreasonable to use either carbohydrate or protein alone as the basic quantity to compare the environmental influences between the food product A and B, in terms of their nutrition. Thus a

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comprehensive nutrient quantity used as the functional unit was important to compare carbon emissions of food product. Recently, many studies considered both the nutrient value and carbon emissions of individual foods or total diets (Drewnowski et al, 2015). However, no research was done to investigate the carbon emissions of different types of CR in China based on different nutrition profiling models. The present study aimed to measure carbon emissions for production of different types of CR foods based on a comprehensive nutrient values in China using a unified carbon emission measurement method and data source, and thus to supply data to assist reduction of carbon emissions from Chinese food systems.

2. Methods

This study was carried out in accordance with the principle of the PAS2050:2011 (BSI, 2011), including three steps, i.e., goal and scope definition, life cycle inventory (LCI), and calculating carbon emissions of product.

2.1 Goal and scope definition

The goal of this study was to analyze the environmental impacts of different types of CR foods to examine the environmental benefits caused by possible dietary changes, thus supplying information to consumers for their dietary choices, about their dietary ecological impact per nutritional unit. In this research, carbon emissions of twenty types of CR food were investigated. The brief information of these CR foods investigated is shown in Table 1.

Table 1: The brief information of twenty types of CR foods.

Food types	Brief information
Rice-based food	1 kg rice in the husk could produce 0.8 kg brown rice, 0.65 kg polished rice with second class, or 0.5 kg polished rice with top grade, respectively.
Wheat-based food	1 kg wheat could produce 0.8 kg wheat berry, 0.8 kg standard wheat flour, or 0.6 kg tailared flour (grade one), respectively.
Maize-based food	Corn kernel, crushing maize, and maize flour were all from corn on the cob, and 1 kg corn kernels could produce 0.6 kg crushing maize, or 0.6 kg maize flour, respectively.
Millet-based food	1 kg millet in the husk could produce 0.75 kg millet or 0.75 kg millet flour.
Avena nuda flour	1 kg avena nuda in the husk could produce 0.8 kg avena nuda flour
Sorghum flour	1 kg sorghum in the husk could produce 0.7 kg sorghum flour.
Buckwheat flour	1 kg buckwheat could produce 0.8 kg buckwheat flour,
Mung bean flour	1 kg mung bean could produce 1 kg mung bean flour.
Adzuki bean flour	1 kg adzuki bean could produce 1 kg adzuki bean.

(1) Functional unit

One of the functional units in this study refers to unit mass (1 kg) of food product that could be prepared and ready to cook in China. In addition, the amount of foods providing 1 kcal of energy was used as another function unit in this research. In order to evaluate the environmental impact per nutritional quantity of, different nutrient profiling models were used to quantify nutritional values as functional unit in this study. In order to comprehensively evaluate the contribution of different nutrients, nutrient reference value (NRV) was used in this research. In the first nutritional profiling model, twenty-one types of macro- and micro-nutrients (protein, fat, carbohydrates, dietary fiber, retinol, VB_1, VB_2, niacin, VC, VE, potassium, sodium, calcium, magnesium, iron, manganese, zinc, copper, phosphorus, selenium, and cholesterol) were selected. The nutritional data of the studied foods are from the Chinese nutrient database (Yang et al., 2009). Equations (1) and (2) were employed to calculate the nutrition relative value of product.

$$NRV_i\% = \frac{X_i}{NRV_i} \times 100\% \qquad (1)$$

$$Nu_{21} = \sum_{i=1}^{21} NRV_i\% \qquad (2)$$

where X_i is the amount of nutrient element i in the food; NRV_i represents the daily reference intake value of nutrient element i in China (Chinese Ministry of Health, 2008); $NRV_i\%$ is the relative nutrition value of nutrient element i in the food, representing the contribution of the nutrient to the reference requirement with respect to the specific nutrient; Nu_{21} the sum of the relative values of the 21 studied nutrient elements in the food. On the other hand, according to dietary guidelines for Chinese residents developed by Chinese Nutrition Society, grains, beans, and tubers food are important food source of protein, carbohydrate, dietary fibre, VB_1, and VB_2 for Chinese. Accordingly, in another nutritional profiling model, the five nutrients were also used to represent trophic function of the foods. Equations (1) and (3) were employed to calculate the relative nutrition value of product.

$$Nu_5 = \sum_{i=1}^{5} NRV_i\% \quad (3)$$

where, Nu_5 represents the total relative nutrition value of the five types of nutrients in the foods.

(2) System boundaries

The system boundaries include the agricultural production process, manufacture process, and transportation process.

2.2 Life cycle inventory

Inventory analysis phase of LCA is to compile and quantify inputs and outputs of a product throughout its life cycle. The carbon emissions of products include direct and indirect emissions. Direct emissions source included CH_4 produced by rice, N_2O caused by fertilization, and CO_2 from energy consumption. Indirect emissions were from the production of fertilizer, pesticide, film, seeds, etc.

Direct carbon emissions from energy burning at the cultivation phase and transportation phase were considered in this study. In this research, the methods proposed by Wang et al. (2015) were used to estimate N_2O emissions from fertilization, and the specific emission factor for N_2O emissions from the total N inputs was from Gao et al. (2011). For the CH_4 emissions from rice cultivation, Eq(4) was used.

$$GHG_{CH_4} = \frac{\sum_j RA^j \times EF^j}{\sum_j PY^j} \times GWP_{CH_4} \quad (4)$$

Where GHG_{CH_4} represents the CH_4 emissions from rice paddies (kgCO_2eq/kg product); RA^j (ha) represents the area of rice paddies in province j in China; EF^j represents the emissions factors of rice paddies in different province j (kgCH_4/ha), which was reported by Wang et al. (1998) and Min and Hu (2012); PY^j represents the yield of rice in province j. Indirect emissions for the foods were generated during producing fertilization, pesticides, agriculture film, diesel fuel, electricity, and seed. The inputs and outputs of a food product throughout cultivation, producing, and transportation processes were.

(1) Crop cultivation

In this research, farming activity data such as amount of fertilization application, seed, energy, and agriculture film per hectare for wheat, rice, maize, and potato were collected from the China Agricultural Products Cost-Benefit Yearbooks (NDRC, 2015). In addition, information related to cropping area and production yield were extracted from the China Rural Statistical Yearbooks (RSEID, 2015) and China Agriculture Statistical Report (MOA, 2014). Cultivation information of sorghum, millet, mung bean, azuki bean, buckwheat, and avena nuda were mainly from Zheng and Fang (2009). In this research, part of machinery operating costs and all of fuel and power cost during cultivation in the China Agricultural Products Cost-Benefit Yearbooks were assumed from farm diesel. In addition, irrigation cost (except water cost) in the China Agricultural Products Cost-Benefit Yearbooks was assumed all caused by electricity consumption.

(2) Production and processing

In this research, carbon emissions from processing different CR foods were considered. Cao et al. (2014) investigated the carbon emissions for rice production in Shanghai, and reported that the electricity used for brown rice and polished rice were 0.0102 and 0.0264 kWh/kg rough rice. For processing of the other foods, survey data was mainly used. Medium-scale mill and crusher were used to produce different kinds of foods. The energy consumption to produce 100 kg wheatberry, standard wheat flour, tailored flour with grade one, crushing maize, maize flour, sorghum flour, millet, millet flour, buckwheat flour, avena nuda flour, adzuki bean, and mung bean flour were 9.38, 9, 9, 20, 30, 32.14, 6.70, 20.09, 9.38, 28.13, 10.40, and 10.40 kWh.

(3) Transportation

For the food transportation, only the GHG emissions of fuels were considered. For this stage, many assumptions are often used. In China, there are 13 main grain producing districts including Liaoning, Hebei, Shandong, Jilin, Neimenggu, Jiangxi, Hunan, Sichuan, Henan, Hubei, Jiangsu, Heilongjiang, and Anhui, which produce most of total grains output in China. In this research, two-thirds of grains produced in the districts were assumed to be consumed by local people, and the others were consumed by people in other provinces in the country. The distance between the two provincial capitals was used to represent the transportation distance between the two provinces. The transportation distance in one province was assumed to be 20 km. In this research, average data from China's Ministry of Transport was used (MTPRC, 2015).

In this research, many local emission factors were used. The emissions factors of nitrogen, phosphorus, and potassium fertilizers were from the study of Chen et al. (2015). On the other hand, carbon emissions of production and transport of herbicides, insecticides, and fungicides were from published research (Lal, 2004) and more recently (Zhang et al., 2016). The emissions factors of agricultural film, electricity, diesel fuel, and standard coal are 22.72 kg CO_2eq/kg (Ecoinvent database, 2011), 1.03 kgCO_2/kWh (Hou et al., 2012), 102.4 g CO_2eq/MJ (Ou and Zhang, 2009), and 2.15 kg CO_2/kg (IPCC, 2006). Besides, carbon emissions from seed production came from the study by West and Marland (2002).

2.3 Calculating the product carbon emissions

In this research, the life cycle carbon emissions translated from the primary or secondary activity data by multiplying the emission factor for each activity were compared. In regard to environmental impact assessment, global warming potential according to IPCC (2006) was assessed with a time interval of 100 y (GWP methane: 25, GWP nitrous oxide: 298).

3. Results

Carbon emissions of the CR food products per kg edible portion are shown in Table 2. The results showed that among the studied CR foods, rice-based products, avena nuda flour, and buckwheat flour were associated with higher carbon emissions. In addition, the rankings of carbon emission for CR foods based on different function units (mass, energy, Nu_5 and Nu_{21}) are also shown in Table 2. The rankings of carbon emission based on energy provided by the foods were very similar to those based on mass. That is because major component of the CR foods was the same, carbohydrate. In the studied CR foods, the amount of energy per kg food product provided by azuki bean or azuki bean flour was lower than those provided by the cereal food. Thus, the rankings of azuki bean or azuki bean flour increased. Besides, although carbon emissions per kg corn kernel was much bigger than carbon emissions per kg potato and sweet potato, the results in Table 2 showed that carbon emissions per kcal energy provided by corn kernel was lower than that provided by potato and sweet potato, due to higher energy per kg provided by corn kernel than by potato and sweet potato, and less energy per kg food product from potato and sweet potato compared to the other foods.

Table 2: The rankings of different CR foods based on different function unit

Food types	kg CO_2eq per kg product (ranking)	kg CO_2eq per unit energy (ranking)	kg CO_2eq per unit Nu_5 (ranking)	kg CO_2eq per unit Nu_{21} (ranking)
Polished rice with top grade	3.18(1)	1.85(1)	0.59(1)	0.199(1)
Polished rice with second class	2.45(2)	1.42(2)	0.40(2)	0.097(2)
Avena nuda flour	2.27(3)	1.18(4)	0.24 (5)	0.040(9)
Brown rice	1.97(4)	0.88(5)	0.26(4)	0.041(8)
Buckwheat flour	1.91(5)	1.26(3)	0.20(7)	0.052(7)
Mung bean flour	1.44(6)	0.87(6)	0.12 (16)	0.031(14)
Mung bean	1.33(7)	0.84(7)	0.16 (9)	0.023(17)
Millet flour	1.32(8)	0.74(11)	0.32(3)	0.066(4)
Tailored flour (grade one)	1.32(9)	0.76(9)	0.22(6)	0.069(3)
Sorghum flour	1.28(10)	0.73(13)	0.15(11)	0.033(12)
Azuki bean flour	1.27(11)	0.82(8)	0.12 (15)	0.024(15)
Maize flour	1.26(12)	0.74(12)	0.15(11)	0.053(6)
Millet	1.19(13)	0.66(15)	0.16(10)	0.032(13)
Azuki bean	1.16(14)	0.75(10)	0.11 (17)	0.022(18)
Crushing maize	1.15(15)	0.66(14)	0.18(8)	0.057(5)
Wheatberry	1.02(16)	0.59(16)	0.13 (13)	0.037(10)
Standard wheat flour	1.02(17)	0.59(17)	0.13 (14)	0.036(11)
Corn cob	0.57(18)	0.34(20)	0.07(20)	0.022(18)
Sweet potato	0.22(19)	0.45(19)	0.10 (18)	0.024(15)
Potato	0.18(20)	0.46(18)	0.09(19)	0.016(20)

Considering the nutrition characteristics of CR foods, a comprehensive function unit (Nu_5), calculated by Eq(3) were used to evaluate the carbon emission of the CR foods. The results showed that the rankings of polished rice with top grade, polished rice with second class, and brown rice were 1, 2, and 4, respectively. It indicated carbon emissions of rice-based foods were still high based on the nutrition value. The results also showed that the rankings of avena nuda flour, buckwheat flour, mung bean flour, azuki bean and azuki bean flour were reduced. It was related to that these kinds of food provided more dietary fiber and VB_2. Meanwhile, the rankings of millet, millet flour, crushing maize, tailored flour (grade one), wheatberry, and standard wheat flour were raised. In addition to the five nutrient contents (protein, carbohydrate, dietary fibre, VB_1, and VB_2), other nutrition contents are also important for human health. If other nutrients were obtained from the CR foods, people could eat less foods with high carbon emissions like meat. The ranking based on Nu_{21} was different from the ranking based on mass. When the twenty-one kinds of nutrient content of foods were considered, the rankings of avena nuda flour, brown rice, buckwheat flour, mung bean, mung bean flour, azuki bean, and azuki bean flour were lowered significantly, which was related to that these kinds of food provided more comprehensive nutrition. For example, the amount of fat, dietary fibre, VE, potassium, magnesium, iron, and manganese per 100 g avena nuda flour were 7.2 g, 5 g, 7.96 mg, 319 mg, 146 mg, 13.6 mg, and 4 mg. While the amount of these nutrient content were 1.5 g, 2.1 g, 1.8 mg, 190 mg, 50 mg, 3.5 mg, and 2 mg for the standard wheat flour (Yang et al., 2009). The rankings of tailared flour (grade one), maize flour, crushing maize, wheatberry, and standard wheat flour rose significantly.

The results in Table 2 showed that the rankings based on different function units varied. Energy and nutrient adequacy is the basis of sustainability diets. Although the nutrition-based method was more complex than the mass-based or energy-based methods used, the rankings of foods based on the five or twenty-one nutrient contents could more profoundly demonstrate the impacts of foods. Irrespective of employed function unit, rice-based foods produced higher carbon emissions. On the contrary, sorghum flour, millet, azuki bean, wheatberry, standard wheat flour, corn kernels, sweet potato, and potato produced less carbon emissions. Rice based foods and wheat based foods are staple foods in China. Thus, more consumption choice to wheatberry and standard wheat flour could be a feasible plan to reduce carbon emissions. Meanwhile, the results in Table 2 showed that the rankings of corn kernel, sweet potato, and potato were low, regardless of mass-, energy-, or nutrition-based function unit, which indicated that these foods were environmentally friendly products. Therefore, displacing rice based foods and tailored flour (grade one) by corn kernels, sweet potato, and potato could cut a considerable amount of carbon emissions.

4. Conclusions

The food sector produces large amounts of carbon emissions, which has attracted attention of many researchers. CR foods were consumed in large quantities every year. In this study, the carbon emissions of CR foods including grains, beans, and tubers foods from their cultivation, processing, and transportation phases were investigated. From the point of types of food, rice-based products, avena nuda flour, and buckwheat flour were associated with higher carbon emissions per kg food product. Energy and nutrient adequacy is the basis of sustainability diets. To more accurately illustrate the impacts of consumption choice of the studied grains, beans, and tubers foods on the environment, the carbon emissions of different types of foods were evaluated based on energy and nutrition content. Carbon emissions of product per function unit varied depending on the function unit used. When energy per kcal provided by food was used as the function unit, the rankings of carbon emission for the foods were similar to that when per kg food was used as the function unit. When five kinds of nutrient content of foods was used as the function unit, the rankings of avena nuda flour, buckwheat flour, mung bean flour, azuki bean and azuki bean flour were reduced. When the rankings of grains were developed according to carbon emissions per unit value of 21 kinds of nutrition content, avena nuda flour, brown rice, buckwheat flour, mung bean, mung bean flour, azuki bean, and azuki bean flour went down significantly in the ranking. On the other hand, the results showed that no matter which function unit was used, rice based foods produced more carbon emissions. Finally, the results showed that more consumption choice to wheatberry and standard wheat flour could be a feasible plan to reduce carbon emissions. The increase in consumption of corn kernels, sweet potato, and potato instead of rice-based foods and tailored flour (grade one) could cut a considerable amount of carbon emissions further.

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References

Berners-Lee M., Hoolohan C., Cammack H., Hewitt C. N., 2012, The relative greenhouse gas impacts of realistic dietary choices, Energy Policy, 43, 184-190.

BSI, 2011. Publicly Available Specification (PAS 2050: 2011): Specification for the assessment of the life cycle greenhouse gas emissions of goods and services, <bilans-ges.ademe.fr/sites/default/files/u22/BSIPAS2050Guidetechnique2011.pdf>, accessed 20.02.2017.

Cao L.M., Li M. B., Wang X.Q., Zhao Z.P., Pan X.H., 2014, Life cycle assessment of carbon footprint for rice production in Shanghai, Acta Ecologica Sinica, 34(2), 491-499.

Chen S., Lu F., Wang X. K., 2015, Estimation of greenhouse gases emission factors for China's nitrogen, phosphate, and potash fertilizers, Acta Ecologica Sinica, 35(19), 6371-6383.

Chinese Ministry of Health, 2008. Management Specification of food nutrition labelling, <www.gov.cn/gzdt/2008-01/11/content_856260.htm.>, accessed 20.02.2017.

Drewnowski A., Rehm C. D., Martin A., Verger E. O., Voinnesson M., Imbert P., 2015, Energy and nutrient density of foods in relation to their carbon footprint, The American Journal of Clinical Nutrition, 101(1), 184-191.

Ecoinvent database, 2011. <www.ecoinvent.ch>, accessed 20.02.2017.

Flysjö A., Cederberg C., Henriksson M., Ledgard S., 2012, The interaction between milk and beef production and emissions from land use change–critical considerations in life cycle assessment and carbon footprint studies of milk, Journal of Cleaner Production, 28, 134-142.

Gao B., Ju X. T., Zhang Q., Christie P., Zhang F. S., 2011, New estimates of direct N_2O emissions from Chinese croplands from 1980 to 2007 using localized emission factors, Biogeosciences, 8(10), 3011-3024.

Hou P., Wang H. T., Zhang H., Fan C. D., Huang N., 2012, Greenhouse gas emission factors of Chinese power grids for organization and product carbon footprint, China Environmental Science, 32(6), 961-7.

IPCC (Intergovernmental Panel on Climate Change), 2006. Guidelines for national greenhouse gas inventories, <wwwipcc-nggipigesorjp/public/2006gl/indexhtml>, accessed 20.02.2017.

Lal R., 2004, Carbon emission from farm operations, Environment international, 30(7), 981-990.

MTPRC (Ministry of Transport of the People's Republic of China), 2015. Transportation sector developed statistical bulletin in 2015, <zizhan.mot.gov.cn/zfxxgk/bnssj/zhghs/201605/t20160506_2024006.html>, accessed 20.02.2017.

MOA (Ministry of Agriculture), 2014. China agriculture statistical report, China Agriculture Press, Beijing, 220 ps. ISBN: 978-7-109-21107-0.

Min J. Sh., Hu H., 2012, Calculation of greenhouse gases emission from agricultural production in China, China Population, Resources and Environment, 22(7), 21-27.

NDRC (National Development and Reform Commission of China), 2015. China agricultural products cost benefit yearbooks, China Statistics Press, Beijing, 628 ps. ISBN: 978-7-5037-7448-5.

NBS (National Bureau of Statistics of the People's Republic of China), 2016. China statistical yearbook, China Statistics Press, Beijing. <www.stats.gov.cn/tjsj/ndsj/> accessed 20.02.2017.

Nemecek T., Weiler K., Plassmann K., Schnetzer J., Gaillard G., Jefferies D., García–Suárez T., King H., Milà i Canals L., 2012, Estimation of the variability in global warming potential of worldwide crop production using a modular extrapolation approach, Journal of Cleaner Production, 31, 106-117.

Ou X. M., Zhang X. L., 2009, Fossil energy consumption and GHG emissions of final energy by LCA in China, China Soft Science, 2, 208-214.

Pairotti M. B., Cerutti A. K., Martini F., Vesce E., Padovan D., Beltramo R., 2015, Energy consumption and GHG emission of the Mediterranean diet: a systemic assessment using a hybrid LCA-IO method, Journal of Cleaner Production, 103, 507-516.

RSEID (Rural Social Economic Investigation Department), 2015. China rural statistical yearbook, China Statistics Press, Beijing, 460 ps. ISBN: 978-7-5037-7678-6

Wang W., Guo L., Li Y., Su M., Lin Y., De Perthuis C., Moran D., 2015, Greenhouse gas intensity of three main crops and implications for low-carbon agriculture in China, Climatic Change, 128(1-2), 57-70.

Wang M., Li J., Zheng X., 1998, Methane emission and mechanisms of methane production, oxidation, transportation in the rice fields, Scientia Atmospherica Sinica, 22, 610-621.

West T. O., Marland G., 2002, A synthesis of carbon sequestration, carbon emissions, and net carbon flux in agriculture: comparing tillage practices in the United States, Agriculture, Ecosystems & Environment, 91(1), 217-232.

Xu Z., Sun D. W., Zeng X. A., Liu D., Pu H., 2015, Research developments in methods to reduce the carbon footprint of the food system: a review, Critical reviews in food science and nutrition, 55, 1270–1286.

Yang Y. X., Wang G. Y., Pan X. Ch. (Ed), 2009. Chinese food composition, Peking University Press, Beijing, China, 384 ps. ISBN: 9787811167276

Zhang G., Lu F., Huang Z. G., Chen Sh., Wang X. K., 2016, Estimations of application dosage and greenhouse gas emission of chemical pesticides in staple crops in China, Yingyong Shengtai Xuebao, (9), doi: 10.13287/j.1001–9332.201609.031.

Zheng D. Sh., Fang J. H. (Ed), 2009. Varieties and cultivation of small coarse cereals with high quality, China Agriculture Press, Beijing, China, 389 ps. ISBN: 9787109137493