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REVIEW

Research progress and strategies for multifunctional rapeseed: China as an example

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Abstract

Rapeseed (*Brassica napus*), is an important source of edible oil, animal fodder, vegetables, condiments and biodiesel, and plays a significant role in securing edible oil production worldwide. However, in countries with comparatively low levels of agricultural mechanization, such as China, increasing costs of labor and agricultural inputs are decreasing rapeseed profitability, and hence the area of rapeseed under cultivation. If the value of rapeseed crops is not further increased, the rapeseed growing area will continue to decrease, potentially jeopardizing oil production. Therefore, full exploitation of the existing and potential value of rapeseed is desirable. Different rapeseed products are already utilized in different ways, with more applications currently underutilized. As well as oil extraction from the seeds, the shoot and leaves can be used as vegetables, the roots to absorb soil cadmium for pollution remediation, the flowers for sightseeing and as a source of nectar, the pollen for extracting flavonoids and useful amino acids, the seeds/seed meal for extracting isthiocyanates and other important sulforaphane compounds, the straw and seed meal for fodder, and immature whole plants for green manure. This review summarizes recent research on ways to explore the potential holistic value of rapeseed, by taking as an example the multifunctionality of rapeseed in China.

Keywords: multifunctional rapeseed, sightseeing rapeseed, remediation of cadmium pollution, rapeseed oil, fodder, vegetables

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1. Introduction

Oilseed rape is the general name for *Brassica* oil crops, and includes *Brassica napus* (rapeseed), *B. rapa* (turnip rape) and *B. juncea* (Indian mustard). Oilseed rape is the second-highest yielding oil crop worldwide (http://www.

ers.usda.gov/data-products/oil-crops-yearbook.aspx). In 2013/2014, oilseed rape accounted for 14% of world major oil crop production, and ranked in the top fourteen European agricultural commodities in 2014 (http://www.fao.org/). The latest data from French market analyst agency "Strategie Grains" shows that the global rapeseed yield is expected to reach 70 million tonnes in 2014–2015, a yield increase of 0.4% compared to the previous year. More than 85% of rapeseed oil is produced in the 27 countries in the European Union. The European Economic Community (EEC) ranks first globally for total rapeseed yield (26%), followed by China (20.2%), India (11.3%), Canada (9.3%) and Japan (6.6%) (http://www.indexmundi.com/agriculture/?commodity=rapeseed-oil). In 2011, the major usages of rape oil were for food (67%), biofuels (27%) and oleochemicals (3%) (http://www.cyberlipid.org/index.htm). With increasing global population size, the demand for vegetable oil and feedstock for biofuel as well as seed meal (which contains 35 to 40% protein) for fodder is also increasing. According to the Canola Council of Canada, the demand for global canola oil is estimated to reach 250 million tonnes by 2025, an increase of 67% or 100 million tonnes from current market demand (http://www.canolacouncil.org/). To meet this market demand, many countries will need to either increase the cultivated area of rapeseed or enhance the rapeseed yield per unit area.

However, in countries with low levels of rapeseed mechanization, the comparative benefit to farmers of growing rapeseed has decreased, negatively affecting farmer perceptions of this crop and shrinking the cultivated area of rapeseed. In the present situation, the usage of rapeseed only for oil is unlikely to change the trend of decreasing cultivated area. Only by developing the value of rapeseed products across different markets, increasing the product value and the usage of raw materials, can farmers gain more net profit, changing grower enthusiasm and improving market vitality. Therefore, this review focuses primarily on the development of multifunctionality in rapeseed crops, using the case of China to provide an important reference for innovation of the canola industry.

2. Edible oil

The major use of rapeseed is as edible oil. Edible oil-quality oilseed rape (with low seed glucosinolates and erucic acid) is referred to as canola, and canola oil has distinct advantages over other rapeseed oil types. Firstly, canola oil contains on average only 7% saturated fatty acids, which is the lowest of the commonly consumed oils: corn oil has 13% saturated fat, olive oil and soybean oil have 15%, palm oil has 51% and sunflower oil has 12%; animal oils like lard contain 43% (http://www.canolacouncil.org/media/514518/dietary_fat_english.pdf). The major unsaturated fats in canola oil are oleic acid (C18:1) at 61%, linoleic acid (C18:2) at 21% and alpha-linoleic acid (C18:3) at 11% ("Comparison of Dietary Fats Chart", Canola Council of Canada, Retrieved 2008-09-03, http://www.canolacouncil.org/media/514518/dietary_fat_english.pdf). These unsaturated fats can reduce both total cholesterol and 'bad' cholesterol (low-density lipoprotein (LDL)) without changing the amount of 'good' cholesterol (high-density lipoprotein (HDL)), helping to prevent cardiovascular diseases (Palomaki *et al.* 2010; Iggman *et al.* 2011; Baxheinrich *et al.* 2012). High oleic acid, low alpha-linoleic acid (HOLL) canola cultivars have also been released that produce oil suitable for deep-frying and long-term storage, due to their high stability (Przybylski *et al.* 2013). HOLL canola is already well established in many countries. For example, in Canada, HOLL canola varieties currently account for approximately 15% of the canola acreage (http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2010/09).

In China, rapeseed oil, as the largest source of vegetable oil, accounts for 45–50% of national oil production. Currently, the cultivated rapeseed area in China is around 1.35 billion ha, producing 12–13 million tons of seeds, 7–8 million tons of seed meal, and about 4.5–5 million tons of oil. However, the supply of rapeseed oil still cannot meet the demands of the edible oil market. The self-sufficiency rate in China for rapeseed oil is less than 40% (Yin and Wang 2012), much lower than grain self-sufficiency (95%) (http://english.agri.gov.cn/overview/201301/t20130128_10644.htm). Moreover, the cultivated rapeseed area in China is still shrinking. This is due to several reasons. Firstly, rapeseed profits have been declining recently due to large increases in the cost of planting rapeseed, including labor, pesticides, herbicides and fertilizers. Because of China's urbanization, large numbers of farmers have been moving to the big cities looking for jobs, causing severe labor shortages in rural areas and hence increasing the labor costs. However, the price of canola oil has not increased correspondingly and has remained steady at 4.6 to 5.4 CNY (Chinese Yuan) per kilogram (kg). If canola seeds are priced at 5.4 CNY kg^{-1} and each hectare produces 1875 kg, the gross profit per hectare is 10 125 CNY. The average labor cost is approximately 6 300 to 7 650 CNY ha^{-1} (Table 1), and the average cost of seeds, fertilizers and pesticides per hectare is approximately 2 700 CNY, meaning the net profit per hectare is around –225 to 1 125 CNY ha^{-1}. For most farm families who only have 30–45 ha of land, the profit from planting rapeseed for one year is much lower than a year's wage working in the big cities. Secondly, the level of mechanization in rapeseed cultivation in China is very low: there is a shortage of adapted cultivars with suitable traits for mechanized production, as well as a shortage of good quality, affordable equipment. Fortunately, the technology and equipment needed for mechanization of oilseed rape harvesting are currently under development.

In fact, the rapeseed industry still has large potential for improvement in China. Firstly, the cultivated area can be further expanded. China has about 2.25 billion ha of fallow fields, around 0.75 billion ha of which can be used for planting rapeseed, depending on the characteristics of the canola cultivars as well as the climate and irrigation conditions (http://www.chinanews.com/cj/2010/08-19/2477182.shtml). Moreover, replacing the currently grown *Brassica rapa* cultivars with special early-maturing *B. napus* varieties (with ripening periods of 180 to 200 days) could further increase the rapeseed area to 20 million ha in the double rice cropping regions. Secondly, due to global warming, the area suitable for rapeseed cultivation has also expanded to the north and west. Thirdly, large-scale cultivation of rapeseed has gradually increased in popularity. With the encouragement of Chinese government policies, previously fragmented lands belonging to rural cooperatives, individual families and enterprises are being combined. For example, in Jiangxi Province in 2014, the number of families owning over 40 ha was 15, the number owning over 20 ha was 25, and the number owning more than 4 ha was 200. Fragmented land and smallholdings are being rapidly centralized (information provided by Jiangxi Agricultural Technology Extension Station). Fourthly, the number of research enterprises aiming to develop machinery for mechanized rapeseed planting is also increasing. Furthermore, under the support of Chinese government policies, farmers are subsidized 30% of the purchase costs for buying machines, reducing the economic burden on farmers. As well, supported by national programs, an annual demonstration of mechanized cultivation will be carried out in the main planting provinces to promote the spread of planting techniques to increase rapeseed yield.

In future, trends in development in the Chinese rapeseed industry are expected to include breeding of new varieties with a range of useful traits and improvement in current management practices. Firstly, breeding new rapeseed varieties with high oil content is already underway, with rapid recent developments in China. The oil content of rapeseed from Shanxi Hybrid Rapeseed Center has reached 61.53% using the ecological shuttle breeding technique (Guan *et al.* 2013), which is the use of different geographically ecological conditions to breed new varieties, by planting different generations of the hybrid materials in different places in alternate years. The Oil Crops Research Institute of the Chinese Academy of Agricultural Sciences (Wuhan, China) has bred new *B. napus* lines with more than 64% oil content (http://www.oilcrops.com.cn/ArticleView.aspx?id=909). Furthermore, based on the statistics from the National Regional Trials, the average rapeseed oil content increased from 37% in 2000 to 43% in 2007 and continues to keep this level, and some new cultivars with an oil content of more than 49%, such as Zhongshuang 11, have also been released (Yu *et al.* 2010).

A second breeding objective will be to produce new varieties with stable yield. Extreme variations in the current climate, such as low temperatures, and rainy weather in southern China, have caused great damage to agricultural production. Therefore, breeding of new varieties that are less sensitive to light, temperature, water, and nutrient deficiencies is important to ensure rapeseed production *via* increased adaptability to climate variability.

Thirdly, breeding varieties suitable for mechanization is required to accelerate the development and promotion of the related machinery. In China, varieties are considered good for mechanized cultivation when they are resistant to lodging, diseases, cracking and herbicides, and have the traits of late sowing and precocity. The flowering times for plants within that variety should also be synchronized and the plant architecture should be compact for high density planting.

An additional objective is to breed special early-maturing varieties to fill the planting gap in the double cropping system, and to expand the area of rapeseed planted in

Table 1 Labor costs for different farming operations in China.

Farming operation	Traditional operation and labor cost	
	Traditional operation	Labor cost (CNY ha^{-1})
Transplanting/Thinning out seedlings	Manual work	1 500
Weeding	Loosening soil and weeding twice	1 500–2 250
Fertilization	Manual work	150
Insect prevention (Seedling stage)	Manually spraying two to three times	600–900
Boron treatment (Seedling stage)	Manually spraying	300
Ditch cleaning	Manual work	150
Winter fertilization	Manual work	150
Boron treatment (Early flowering stage)	Manually spraying	150
Sclerotinia and insect prevention	Spraying once to twice in flowering stage	300–600
Harvest, drying and transportation	Manual work	1 500
	Total	6 300–7 650

Data from survey questions posed to farmers by Dr. Fu Donghui from Jiangxi Agricultural University, China.

currently fallow fields. New generation high oleic, low linolenic varieties are also desirable: China already has excellent germplasm resources available in this respect, and new combinations of different varieties are also being tested. Development of environmentally friendly varieties should also be a priority: new varieties should have high production efficiency and low resource inputs, as well as sustainability traits such as resistance to drought, pests, weeds, salinity, waterlogging, lodging and freezing, among others, and high utilization efficiency of nitrogen, phosphorous, and potassium fertilizers. Varieties with these traits improve ecological security through reduced requirements for pesticides and fertilizers. Finally, utilization of improved management strategies, such as crop rotation, large-scale and centralized planting will be implemented to increase farmer net incomes.

3. Energy crop

Due to increasing industrialization in developing countries, the demand for non-edible oil is increasing globally. At the same time, petroleum resources are depleting, making energy a strategic national issue. Therefore, the development of clean and efficient bioenergy is imperative. Rapeseed is an ideal crop for biodiesel production for several reasons. Firstly, canola/rapeseed contains around 40% oil and can produce a high yield of oil per unit area. Secondly, rapeseed biodiesel has a lower cloud point (an indicator of the tendency of the oil to plug filters) and pour point (the temperature at which the liquid becomes semi-solid and loses its flow characteristics) than soybean biodiesel, and a much lower cloud and pour point than biodiesel made from animal fats (Peterson *et al.* 1997). Therefore, biodiesel produced from canola or edible rapeseed becomes a gel at a lower temperature than biodiesel from other feedstocks, making canola biodiesel a more suitable fuel for colder regions.

In temperate climatic regions like Europe, rapeseed is an important source of raw materials for biodiesel, and accounts for 50 to 70% of biodiesel production (Iveta and Eva 2013). In 2008, 66% of biodiesel in Europe came from rapeseed, 13% from soybean and 12% from palm oil (Junginger *et al.* 2014). According to the requirements of the EU, biodiesel should be added into diesel for fuel sustainability purposes, accounting for 5.75% of diesel in 2010 (Kavalov 2004), a requirement of 1.4 million tons of biodiesel. With significantly increased demand for biofuels, the demand of rapeseed oil for industrial use has grown rapidly in the EU, from 1.247 million metric tons in 2002/03 (July/June) to 5.791 million in 2008/09 (http://www.ers.usda.gov/topics/crops/soybeans-oil-crops/canola.aspx). In 2010, the domestic consumption of rapeseed oil for biodiesel production accounted for 68.8% of the total rapeseed production in the EU (Iveta and Eva 2013). Such changes in the structure of rapeseed use are attributable to increased biofuel production, which leads to an increase in the sown area of rapeseed and reinforces the role of oilseeds in sowing structure.

However, significantly increased demand for rapeseed for biofuels will also cause pressure on food supplies, thus increasing food prices. Moreover, several technical challenges remain for industrial use of rapeseed. Firstly, industrial rapeseeds contain more long-chain fatty acids than canola, making it slightly more viscous with a higher distillation temperature than the ASTM D6751 specification allows (http://www.extension.org/pages/26629/rapeseed-and-canola-for-biodiesel-production#.VVZmm010y70). To meet this specification, rapeseed biodiesel can be mixed with other fuels (such as canola or soy biodiesel). Secondly, the efficiency of rapeseed biodiesel production can be low, based on internal studies in Poland and The Netherlands. To improve the production efficiency, the fertilizer input and especially nitrogen fertilizer input should be reduced; also the use of by- and waste products should be optimized (Firrisa *et al.* 2014).

In 2007, the Ministry of Agriculture of China issued the "Agricultural Biomass Energy Industry Development Plan (2007–2015) (http://english.agri.gov.cn/). The plan makes it clear that the development of ethanol as fuel should be under the premise of meeting the population food requirements, which restricts the available lands for rapeseed planting and therefore limits the industrial development of non-edible rapeseed oil as bioenergy feedstock. Meanwhile, the plan also advises that saline land, wastelands, fallow fields and other unutilized or underutilized land resources should be systematically developed by moderate planting of sugar cane, sweet sorghum, potato, rapeseed and other energy crops according to the characteristics of the existing land resources, combined with ecological and other agricultural considerations.

Currently, the technology of rapeseed use for biodiesel production is fully developed, but the provision of a stable and reliable source of raw materials is in short supply (Jokiniemi and Ahokas 2013). Therefore, breeding rapeseed varieties that can grow in marginal soils and the establishment of processing equipment for raw materials both have great significance for the development of the rapeseed biodiesel industry in China.

4. Remediation of heavy metal pollution

Heavy metal pollution in soils has already become a worldwide issue. In Western Europe, the number of sites that were affected by heavy metals reached 1400000 (McGrath and Zhao 2003). More than 300000 sites were considered contaminated, and the estimated total number in Europe could be much higher, as Central and Eastern European countries have even more severe pollution problems (Gade 2000). According to government statistics, more than 100 000 ha of cropland, 55 000 ha of pasture and 50 000 ha of forest have been lost because of heavy pollution in US streams and rivers (Rangarsdottir and Hawkins 2005). The problem of land pollution is also a great challenge in China, where one-sixth of total arable land, 45 million ha, has been polluted by heavy metals (Song *et al*. 2013). Based on the statistics, the decrease of food production caused by heavy metal pollution is over 10 million tons. Up to 12 million tons of contaminated food leads to losses of more than 20 billion CNY (Du 2007). Heavy metal pollution has become a major constraint to sustainable agricultural development, and the largest proportion is cadmium (Cd) pollution. More than 2 080 ha of land area is polluted by Cd in China (Liu *et al.* 2007). According to a seven-year survey covering 2.4 million square miles (out of a total of 3.7 million square miles of land area in China), about 16% of the soil and 19% of the arable land in China is polluted, and heavy metals including cadmium, nickel and arsenic ranked as the highest inorganic pollutants in the soil (http://www.wsj.com/articles/SB10001424052702304626304579507040557046288). It was estimated that the total area polluted by Cd in China is more than 11 000 ha, and 11 provinces and municipalities and 25 territories produce Cd-polluted rice (Cd concentration 1.32–5.43 mg kg^{-1}) (Han *et al.* 2009). Cd shows diverse toxic effects, including particularly protracted biological half-life (about 20–30 years in the human body), as it is difficult to excrete from the body and shows dominant and lasting storage in soft tissues (primarily in the liver and kidneys) (Goyer *et al.* 1995). After several years of chronic accumulation, significant Cd poisoning symptoms can occur, and 0.35 to 0.5 g of Cd in the human body would lead to death (Waalkes 2003).

The methods for restoring Cd-contaminated soil include engineering restoration, chemical control, agro-ecological restoration and bioremediation technology. One important respect of bioremediation is phytoremediation, which involves clearing soil Cd using plants. Plants are able to absorb Cd in the soil through their root system, and transfer the Cd to the above-ground biomass that can be removed when plants reach the maximum vegetative growth stage. Compared with traditional chemical and physical techniques, phytoremediation is environmentally friendly, can maintain soil productivity and does not generate secondary pollution (Alexander *et al.* 1987).

Rapeseed is one of the best choices for Cd pollution phytoremediation, due to several distinct advantages. Firstly, rapeseed has excellent heavy metal accumulation capabilities, with a superior absorption capacity of up to 2 000 ppm for Cd (Qin *et al.* 1998; Ru *et al.* 2005; Xiang *et al.* 2009; Zhang *et al.* 2009). Secondly, rapeseed has the advantages of large biomass, easy harvestability and strong climatic adaptability. Because rapeseed is the only major winter crop grown in China, growing rapeseed in winter would not take away land area from rice cultivation, and hence would not reduce farmers' incomes. There are at least 2.25 billion ha of winter-fallow fields in China that are suitable for the cultivation of rapeseed. Thirdly, rapeseed oil can also be used in industry. Screening for new genotypes that have seeds with normal Cd levels but accumulate high Cd levels in the straw could not only assist in removing Cd pollution but also increase farmer incomes. Finally, rapeseed cultivation techniques are simple, easy to carry out and promote uptake. Therefore, using rapeseed for remedying Cd contamination in soil is efficient, economically and environmentally friendly, and has broad prospects for use.

There are several optimal ways to use rapeseed to alleviate Cd pollution. Firstly, new and existing varieties should be screened for increased capability to uptake and accumulate Cd, by growing plants in soils with different Cd concentrations. If the Cd concentration in the seeds exceeds the standard, both the seeds and straw can be used for raw material to produce biodiesel. If not, the seeds can be used for edible oil. Secondly, a workable, low cost, high efficiency Cd control technology system that can be accepted by the masses and the government based on various costs and environmental factors should be established. In addition, parts of China have soils with lower metal content, but which still exceed the standard: for these soils, new rapeseed varieties with lower Cd absorption should be screened, especially those that show lower Cd accumulation in the seeds.

5. Forage crop

The global livestock sector is developing rapidly, with an annual growth rate of up to 1.5% from 1997 to 2015 (http://www.fao.org/docrep/005/y4252e/y4252e07.htm). Because of this rapid increase in livestock production, the demand for forage supplies has also increased dramatically. For example, in China, the total output of industrial feed reached 1.62×10^8 tons with a value of 4.936×10^{11} CNY in 2010, with an average annual growth rate of 8.6% in tonnage and 12.5% in value production since 2005 (http://www.moa.gov.cn/govpublic/XMYS/201110/t20111012_2355459.htm). The portion of feed grain used for forage is increasing year-by-year, causing competition between forage and food. As of 2010, 36–37% of grain was used for feed (with pig feed accounting for 60%), and the proportion of feed grain is estimated to reach 43% in 2020 and 50% in 2030 (Ren *et al.* 2011). Therefore, broadening forage sources plays an important role in food security. Forage rapeseeds are high quality feed ingredients, and can provide quick and abundant feed. Forage *Brassica* types include not only oilseed rapes but also radish, turnip, broccoli, Brussels sprouts, swedes, cabbage and cauliflower. Because of the high amount of crude protein (15 to 25% in rapeseed leaves and 9% to 16% in the bulbs of turnips and swede) and high levels of metabolisable energy (11 to 14 MJ ME kg^{-1}) they contain, these *Brassica* crop types yield excellent livestock weight gains when used as feed. The average daily weight gain for lambs is 150–250 g $head^{-1}$ d^{-1} and 0.8–1.2 kg $head^{-1}$ d^{-1} for cattle by forage rapeseed feeding (Ayres 2002). As well, the relatively low cost of producing forage rapeseed makes this crop a very promising option for quick feed.

There are two major ways of using rapeseed as feed. The first is to use the rapeseed meal. Canola meal with low glucosinolates (≤30.0 μmol g^{-1}) is an excellent source of protein because it can be incorporated into feed at a higher ratio than rapeseed meal, which has a bitter taste and can cause liver and thyroid problems when used at high levels. Oilseed meal accounts for 60% of rapeseed seed weight and contains about 40% protein (Newkirk *et al.* 2003), three to four times as much protein as rice and wheat (Fu 2007). In demonstration trials for the five largest dairies in China, compared with soybean meal, canola meal increased the milk production for two operations out of five and decreased the feed cost for another two (http://www.producer.com/2012/02/china-develops-taste-for-canola-meal%E2%80%A9/). Canola and rapeseed meals are the second most commonly traded protein ingredients after soybean meal (Newkirk 2009), and China is a growing market for all kinds of oil seed meals because of increasing demand for protein supplements. Canada exported 1.8 billion USD worth of canola and canola products to China in 2010, and 303 000 tons of Canadian canola meal were imported to China in 2012, according to the Canola Council of Canada (http://www.reuters.com/article/2014/03/21/canola-meal-canada-china-idUSL2N0MI0S120140321).

The second way in which rapeseed can be used as feed is by using the rape straw as a feed source. The rape straw yield is about three to four times that of the seed yield, and the annual rape straw yield in China is estimated to be 18–20.4 million tons (Song *et al.* 2009). In Northwest Chinese provinces, such as Qinghai, Gansu, Xinjiang and Mongolia, the lack of water and winter-feed restricts the development of local animal husbandry. To supplement the poor local winter feed, reduce water and soil erosion as well as reduce dust storms, canola can be planted in late July after harvesting the wheat from the previous winter season (Fu *et al.* 2004). In late October and early November, a large amount of rape straw will be harvested; the yield per hectare can be up to 45 tons, which is equivalent to the amount of feed required for two sheep in one year. Professor Fu Ting-dong from Huazhong Agricultural University of China has achieved good results in promoting and demonstrating this wheat cropping/forage rape system in the northwest regions of China (Fu *et al.* 2004). The protein content of forage rape is comparable to that of legumes, but after wheat cropping (when the temperature falls), the grass yield from forage rape is 1/2 to 1/3 higher than that obtained from legume forage, and the protein yield from forage rape is significantly higher than that from legume forage (Table 2) (Fu *et al.* 2004). Therefore, the development of rape forage has great significance in northwest China. In addition, rape forage can also be grown in orchards, fallow fields and flood land in the South China as food for chickens, pigs, cattle, sheep, rabbits, ducks, and geese. However, two major issues need to be addressed. Firstly, new forage rape varieties are needed with fast growth, large leaves and biomass, low fiber content, high protein and soluble sugar content of leaves and easy flowering. Secondly, demonstration and promotion of cropping patterns, planting techniques, mechanization and other supporting technologies to reduce the cost is required.

Although China produces large amounts of rape straw, the utilization of the straw sources is far from optimal. The way that farmers handle the rape straw is traditionally to burn it in the field, and hence the straw cannot be fully utilized. What is more, this handling method also results in fire and air pollution, causing environmental problems and subsequent economic losses. In addition, fog and haze in China has occurred frequently in recent years with increasing severity and length, and is known to be closely related to the soot particles produced by burning straw (Yan *et al.* 2014). Therefore, the Chinese government has recently banned the burning of straw, making the utilization of rape straw as a feed source more urgent. However, the proportion of rape straw used as feed is less than 10% (Yang *et al.* 2012), and fundamental research on the utilization of rape straw as feed is also lacking.

Crude protein is an important indicator to evaluate feed quality. The crude protein of rape straw (5.24%) is significantly higher than that of wheat straw (3.6%) (Bhuiyan *et al.* 2002; Khan and Mubeen 2012), corn stalks (5%) (Bi 2010), as well as higher than the average for feed straws used for ruminants (2.57%) (Cui *et al.* 2012). Therefore, the utilization of rape straw as roughage for ruminants has great potential. However, there are also some challenges. Firstly, rape straw has high crude fiber content and a solid ester bond structure between the cellulose and lignin, resulting in low digestion efficiency for ruminants. Studies have shown that the rape straw after simple crushing has poor palatability, and that replacing a certain portion of roughage with rape straw in cattle feed lowers intake and digestion efficiency of the feed, thus reducing beef production performance. To improve palatability and nutrient digestibility, the rape straw can be treated with ammonia: treating rape straw with 30%

water and 3.5% ammonia urea achieves the best results, with significantly increased protein availability compared to the untreated control; as well as reduced neutral detergent fiber (NDF) and acid detergent fiber (ADF) (Huang 2013). Adding 40% ammonia-treated straw rape to roughage can increase cattle weight and lower the feed conversion ratio (Huang 2013). Further, processing the straw rape at 160 to 200°C under high pressure steam for one hour can increase the degradation rate, although not the degradation of insoluble residues (Alexander *et al.* 1987). Use of a normal pressure microwave heating technique assisted by NaOH pretreatment can increase the hydrolysis of rape straw to 28.09%, which is 2.75 times higher than the untreated rape straw (Li *et al.* 2012). Another important concern is that natural rape straw has a loose, non-compact texture, making transportation and storage very inconvenient. An approach to this would be to breed for straw with optimized agronomic characteristics. Without affecting the lodging rate, breeding new varieties of rapeseed with brittle rods (low fiber and low lignin) and high protein content would improve the utilization efficiency of rape straw as feed.

6. Rapeseed as a sightseeing attraction

The improvement in living standards across China has prompted rapid development in agriculture and horticulture for leisure and tourism purposes. Utilization of rapeseed as a sightseeing crop has several advantages. Firstly, rapeseed flowers are golden, a color which is highly prized culturally and associated with nobility and prosperity in China. When fields or contiguous rapeseed beds are flowering, a golden sea of flowers is formed, with high visual impact. Therefore, rapeseed is highly suitable for sightseeing and has large ornamental value. Growing rapeseed as an ornamental crop can also help to develop local tourism: visitors who come to enjoy the flowers also spend money on food, accommodation and shopping, thus stimulating local economic development and increasing the employment possibilities as well as income of the local people. Secondly, the cultivation of rapeseed does not require difficult or complicated techniques, and the cost is relatively low compared to other ornamental flowers. In addition, rapeseed has a long flowering period of about 30 d. In fact, the length and initiation of the flowering period are closely related to temperature. Low temperatures and early flowering can extend the length of the flowering period. Therefore, rapeseed is an ideal ornamental crop for tourism.

There are currently ten main attractions based on rapeseed flowering in China: Wuyuan in Jiangxi, Hanzhong in Shanxi, Luoping in Yunan, Anshun in Guizhou, Jingmen in Hubei, Shitan in Anhui, Tongnan in Chongqing, Xinghua in Jiangsu, Ruian in Zhejiang and Menyuan in Qinghai. To take the example of Wuyuan: Wuyuan is considered to have the most beautiful countryside in China, and ornamental rapeseed comprises one of the most representative landscapes in the Wuyuan area, with rapeseed grown over about 1 200 ha. In 2011, the income from tourism was about 2.896 billion CNY, accounting for 51.5% of the county's GDP (Gross domestic product) (Zhang 2014). If the flowering period can be extended, this income could be greatly increased. Therefore, extending the flowering period is a major target for ornamental rapeseed.

Several chemical reagents can also be used to regulate the flowering period. Growth promoting agents such as gibberellin and cytokinins can promote plant growth, flower bud differentiation and early flowering. Plant growth retardants such as paclobutrazol and chlormequat can regulate the flowering time, extending the viewing period and preventing leggy and dwarf plants. Different species require different agents to regulate flowering. Supported by the Jiangxi Provincial Department of Science and Technology, China, we are currently trialing fertilization and spraying with chemical reagents in order to identify chemicals that can extend the rapeseed flowering period by up to 5 days, and determining the best spraying period, dosage and methods to establish a system to prolong the rapeseed viewing time.

Furthermore, extending the flowering time can also be achieved by breeding new varieties. The goal for breeding new ornamental varieties is to screen for long flowering period, bright color, more flowers with large petals, and a plant height of not less than 1.5 m. We are now screening for new ornamental varieties and studying fertilizing strategies, including application periods and nutrient ratios, in order to establish a standardized fertilization system. Cultivars with different flower colors, such as white, milk white, red, and even purple, are also welcome for touristic purposes.

7. Green manure

Extensive use of fertilizers leads to soil acidification and compaction, reducing the organic content, water and fertilizer capacity. Green manure refers to the use of plants for fertilizer. As a complete biological nutrient fertilizer, it can provide rich nutrients for the soil. Therefore, green manure plays an important role in improving soil physical and chemical properties, promoting soil microbial activity, increasing soil fertility and enhancing crop yield and stress tolerance.

Rapeseed plays an essential role in crop rotation. There are many biological and agronomic advantages to using rape for green manure or in rotation with other crops. Firstly, growing rape before rice can increase the rice yield by 6–10% compared to letting fields lie fallow, and also supplements soil potassium (Liu *et al.* 2014; Zhou *et al.* 2015). Secondly, the roots of rapeseed can secrete an organic acid which can help to solubilize the insoluble phosphorus in soil and make it able to be utilized by plants (Chambers *et al.* 1996). Thirdly, rapeseed has a short life circle, flexible seeding time, wide adaptability and strong stress resistance. In addition, as a winter oilseed crop, rapeseed will not compete with summer crops such as corn, soybean, rice and cotton in terms of land usage. Therefore, utilization of rapeseed as green manure has great potential.

Recent studies have highlighted the importance of using rapeseed as green manure. An increasing trend of soil organic matter under the rotation cropping of double rice and rape has been observed, which would significantly enhance rice yield (Gao *et al.* 2011). Rapeseed rotation also increased microbial activity and beneficial soil bacterial populations in potato field trials (Bernard *et al.* 2012). Meanwhile, rapeseed green manure or rape rotation can also inhibit the incidence of disease. For example, studies have confirmed that rape manure can suppress apple root infection by *Rhizoctonia* spp. and *Prtylenchus penetrans* in apple orchards (Mazzola *et al.* 2001), reduce common root rot caused by *Aphanomyces euteiches* in pea fields (Williams-Woodward *et al.* 1997), and reduce populations of *Xiphinema americanum sensu lato* in temperate orchards (Halbrendt 1996). In addition, rape green manure could also suppress weeds and increase yield of crops (Boydston and Hang 1995).

In conclusion, a simple and efficient green manure operating system needs to be created. This system should include species and genotype selection, management strategies, treatment timing and methodologies. As well, scientific evaluation of the effect of using rapeseed as green manure on crops should be carried out, including results after fertilization, subsequent soil fertility and microorganism composition in the soil.

8. Vegetable crops

Brassica napus is a natural hybrid between *Brassica oleracea* and *Brassica rapa* (UN 1935), which are both important vegetable crop species. In fact, many *Brassica* species can be eaten as vegetables, although the use of rapeseed as a leaf vegetable crop has not been previously developed. In the Yangtze River Basin in China, fewer winter vegetables are available than summer vegetables. Therefore, rapeseed as a winter crop has great economic potential (Shi *et al.* 2009). Rapeseeds are low-fat vegetables that contain calcium, iron, vitamin C and carotene and other nutrients. The calcium amount in rapeseed is the highest of the green leafy vegetables, and the vitamin C content in rapeseed is more than twice that of cabbage (Shi *et al.* 2009). Rapeseeds also contain dietary fiber which can be combined with cholate and cholesterol in food to help reduce the absorption of lipids (Zhang *et al.* 2010). Double low rapeseed can be either be eaten directly or frozen for storage or transportation. It can also be deep-processed into dehydrated vegetables, increasing its value and extending the supply season. To be specific, when the rapeseed is bolting and about 30 to 40 cm in height, the top 20 cm of the sprouts can be cut as vegetables. Yield per hectare is estimated to be 3.75 tons of vegetable sprouts, and the price per kg is expected to be 4 CNY. Therefore, a 1 ha field of rapeseed can produce 15 000 CNY and minus labor fees, the income from 1 acre for farmers is about 600 CNY. After cutting the sprouts and applying fertilizer, the rapeseed production will not be reduced; on the contrary, the yield can be increased by up to 15% (Li 2007). Because the main inflorescence is cut off, the apical dominance is removed, increasing the number of branches and postponing the period of reproductive growth by 3 to 4 d. The future aims for using rapeseed as a vegetable are as follows: firstly, to breed new rapeseed varieties with better taste, higher sugar content and less fiber; and secondly, further processing the vegetable sprouts to produce more varieties of products, like frozen vegetables and pickles, which can be stored for longer periods of time and easily shipped long distance.

9. Honey crop

Rapeseed is not only an important oil crop but due to several native advantages can also be used as a nectar plant. Firstly, rapeseed is widely distributed in China with comparatively long flowering time, which is helpful for producing and collecting nectar. Secondly, rapeseed nectar contains high amounts of good quality sugar. Thirdly, the odor of the nectar from rapeseed flowers, which is attributable to compounds such as 3-phenylpropionic acid and phenylacetic acids, is very attractive to bees (Ruisinger and Schieberle 2012). In addition, rapeseed flowers can produce a large amount of nectar. Anywhere from 350 000–700 000 rapeseed plants can be grown on one hectare of land, and over four weeks of flowering time, each plant can produce more than 100 flowers (Mussury and Fernandes 2000). Therefore, rapeseed can yield large amounts of plant nectar in a limited land area. Furthermore, rapeseed flowers can be pollinated *via* bees, which can also improve rapeseed yields (Rosa *et al.* 2010, 2011). Interestingly, increasing the density of bee nests in rapeseed fields can increase rapeseed production. According to previous research, seed yields with bee pollination can be more than 30% higher than yields without pollination (Xie *et al.* 2011). The chemical composition of the pollen collected by bees has also drawn increasing attention. The pollen from rapeseed collected by bees can be used as a natural food and medicine to strengthen the human immune system to fight against cancer and other diseases. According to the research, steroids extracted from pollen can affect the viability of human cancer cells, especially prostate cancer PC-3 cells (Wu *et al.* 2004; Wu *et al.* 2009). Canola flower pollen hence contains beneficial elements with significant therapeutic effects on prostate disease (Feng *et al.* 2011; Zhu *et al.* 2011). Therefore, using flower pollen for treating advanced prostate cancer shows promise for the future. However, the exact chemical components with medical effect still need to be identified, and the pharmacological mechanisms underlying this effect elucidated. This research would lay a solid foundation for developing rapeseed honey with highly effective medical components.

10. Glucosinolates and anti-carcinogenic compounds

According to the data released by the Chinese Cancer Registration Center, in 2015, the number of new cancer cases was about 4.292 million (Chen *et al.* 2016). An average of 8 474 people were confirmed to have cancer per day, and about six people were diagnosed with cancer per minute (Chen *et al.* 2014). By 2020, the total annual number of cancer cases is estimated to reach 6.6 million, with 3 million of these cases expected to die of this cancer (Herr and Büchler 2010). Eating food with anti-carcinogenic compounds may play an important role in reducing cancer risk. Many scholars believe that eating cruciferous vegetables such as broccoli, cauliflower, cabbage, etc. can greatly reduce the incidence of cancer (Verhoeven *et al.* 1996; Herr and Büchler 2010).

The reason cruciferous plants are postulated to have anti-carcinogenic effects is that they contain glucosinolates. When the plant is ground or chewed, the glucosinolates will be hydrolyzed into compounds such as isothiocyanate, various cyanate compounds, nitriles or oxazolidine 22-thione, of which isothiocyanato cyanate esters are the most important class of compounds (Wu *et al.* 2009). In recent years, it has been found that isothiocyanate compounds (such as sulforaphane and phenethyl isothiocyanate) exhibit strong anti-cancer activity. Sulforaphane (1-4-methanesulfonyl isothiocyanate butane, sulforaphane, SF) is one of the best anti-carcinogenic substances in vegetables (Chung *et al.* 2000; Hwang and Jeffery 2003). Sulforaphane can also inhibit cancer cell reproduction (Pawlik *et al.* 2013), induction of apoptosis (Herman-Antosiewicz *et al.* 2006), DNA damage and so on, with specific results found for inhibition of skin cancer, liver cancer and colon cancer (Ramirez and Singletary 2009). Although sulforaphane can be chemically synthesized, the synthesized product may still contain other by-products that may be harmful to the human body. Only 0.5 g of sulforaphane can be extracted from 1 kg of broccoli.

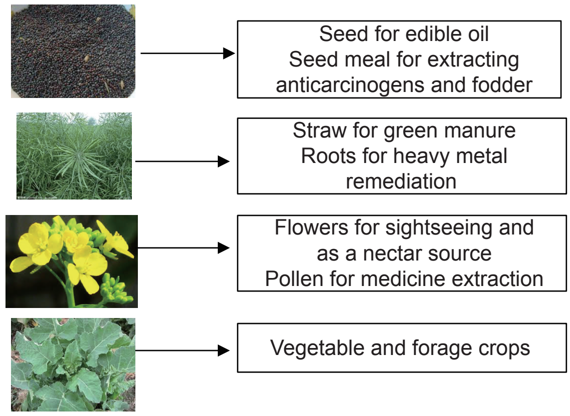

Fig. 1 Development of multifunctionality in rapeseed.

Wu *et al.* (2009) characterized seeds of 28 *Brassica* cultivars, revealing that 13 genotypes contained sulforaphane. Several cultivars (Dragon No. 1, Dragon No. 2 and green broccoli) had relatively high levels of sulforaphane (1 575.5, 1 391.0 and 1 126.9 mg kg^{-1}, respectively) (Wu *et al.* 2009). Firstly, to use rapeseed as a source for promising anti-cancer drugs, we need to develop new extraction methods with high efficiency, low cost and low levels of toxic chemical residues. Secondly, more work needs to be done in characterising anti-carcinogenic components of the isothiocyanate compounds, particularly those other than sulforaphane, and the mechanism of how these components work on cancers should also be further explored.

11. Conclusion

As an important oil crop, rapeseed plays a significant role in edible oil security. However, due to increased labor and input costs, farmer interest in cultivating rapeseed is declining year after year in China. This article describes how to develop the potential value of rapeseed in all aspects, including the breeding of new varieties, the standardization of cultivation and the formation of industrial chains to maximize the potential economic value of rapeseed. The use of rapeseed as an edible oil, vegetable, energy, forage, green manure and honey crop is detailed, as well as uses in extraction of glucosinolate compounds, as a sightseeing attraction and for remediation of heavy metal pollution (Fig. 1).

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