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Review

Chinese Baijiu distiller's grains resourcing: Current progress and future prospects

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ABSTRACT

Distiller's grains (DGS) as a typical organic solid waste in Chinese Baijiu production, with high water content, nutrient and various high-value components. Conventional waste management causes environmental issues and bioresource wasting. With the development of Chinese Baijiu companies, the demand for effective DGS treatment is urgent. There were various approaches for DGS resourcing, such as feeding, high-value components extraction, biogas production and composting. This review focus on the efficiency and existed limitations of these methods, includes the effects of feeds in livestock and poultry breeding, extraction efficiency and utilization, biogas yield and purity, and substance variation and stabilization in composting. As a prospect, process for DGS cascade and full utilization should be designed in further study. Combining and organizing the methods in different studies, decreasing the waste and discharge in process, optimizing the approaches in high value component extraction, promoting the utilization in different production, the value of DGS can be increased. The remained materials after cascade utilization can be further treated by full utilization in bioresource energy and composting. Therefore, Chinese Baijiu companies can achieve zero organic solid waste discharge and cleaner production.

1. Introduction

Currently, Chinese Baijiu is made from sorghum and wheat by solid-state fermentation (Jin et al., 2017; Li et al., 2019). The processes of Chinese Baijiu production are shown in Fig. 1. Sorghum as the raw material mixed with *Daqu* powder for successive spread out, pile up and fermentation. Chinese Baijiu is distilled by the fermented substance. *Daqu* powder is made of fermented wheat and inoculates with various microorganisms (such as *Leuconostocaceae, Thermoascus,* and *Thermomyces*), which can be recognized as microbial agents for sorghum fermentation (Xiao et al., 2021). The substance mixed with sorghum and *Daqu* is named as *Jiupei*. Before the solid-state fermentation in pile, *Jiupei* should be spread out (less than 1 h) and then pile up (2–3 days) for microorganisms accumulation and growth (in aerobic condition). After 30–40 days anaerobic pits (or jars) fermentation, *Jiupei* mixed with rice husk (for steam circulation) in distiller to product Chinese Baijiu. After distiller steaming, the residual component of the grain kernel with rice husk is DGS (Fig. 2). Starch in raw materials is consumed by micro-organic for alcohol production. However, there are abundant remained proteins and fibers in DGS cannot be transformed/steamed into Chinese Baijiu due the limitation and low efficiency of traditional distillation technology and solid-state fermentation (Jin et al., 2017).

Some reports indicated that roughly more than 100 million tons of DGS as waste are generated after Chinese Baijiu production every year (Zhi et al., 2017b; Zhou and Zheng, 2013). Conventional organic solid wastes management causes environmental pollutants. Biogas emission in landfill, for example, causes odor, leachate and greenhouse effect

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Abbreviations

1,1-diphenyl-2-picrylhydrazyl DPPH
2,2′-azino-bis-(3-ethylbenzothiazoline-6-sulfonic acid) ABTS
2,2′-azobis(2-amidinopropane) dihydrochloride AAPH
Carbon/Nitrogen ratio C/N
Chemical Oxygen Demand COD
Conventional feed group CK group
Crude Protein CP
DGS containing 4% yeast culture YC
Dietary fibers DF
Distiller's grains DGS
Distillers' dried grains with solubles DDGS
Dry matter DM
Humus index HI
Insoluble dietary fiber IDF
Low molecular weight LMW
Methane CH4
Microbial fermented feeds MFF
Organic loading rates OLR
Oxygen radical absorbance capacity ORAC
Soluble dietary fiber SDF
Soluble soil carbon WSC
Soluble soil nitrogen WSN
Volatile fatty acid VFA
Volatile solid VS

(Chew et al., 2021). In addition, hazardous components, such as pathogen and heavy metal, cause contamination in soil and further risks in agriculture and food safety (Chia et al., 2020). DGS waste resourcing is an effective sustainable development approach to decreases the environmental risk and pollutants.

DGS contains various unhydrolyzed and unfermented components (Table 1). Some components with bioactive functions and high nutrient values (such as protein and peptide) can be classified as high-value components. At present, similar with liquor vinasse resourcing, approaches for DGS utilization can be majorly divided into four categories 1) Feeding, 2) High-value component extraction, 3) Biomass energy production and 4) Agriculture application (composting and soil conditioner) (Fig. 3) (Wang et al., 2015, 2020; Wei et al., 2019; Xu et al., 2009; Zhi et al., 2016, 2017b).

It should be noticed that, even though feeding took the dominant status in DGS utilization, the demand from the livestock industry may become restricted as limited nutritive value and potential risk of in DGS feeds, such as remained alcohol and grain mycotoxin issues (Giuntoli et al., 2009). In order to maximize the treatment capacity and value of the DGS resourcing, value-added utilization and fully utilization approaches should be promoted (Gudka et al., 2012; Jin et al., 2014). Increasing the approaches and application methods for DGS resourcing, Chinese Baijiu companies can drop the waste discharge and product high value products (such as bioenergy and health care products). Finally, cleaner production and material recycling can be achieved in the industries.

This review summarized some existed approaches in DGS resourcing and analyzed the efficiencies and challenges. In this review, major discussed approaches included feed production, high-value component extraction, biogas production and composting (Table 2 and Fig. 3). Furthermore, as future prospect, a flow for DGS cascade and full utilization processes was designed. The aim of cascade and full utilization is the value of DGS resourcing increase and the amount of material recycling maximization.

2. DGS utilization approaches and techniques

2.1. Feed production

DGS and Distillers' dried grains with solubles (DDGS) are alternative components in livestock and poultry feeds. DGS and DDGS both are residual (non-fermentable) components of the grain kernel in ethanol production. However, DDGS is the residual in bioethanol production without risk huck (Pahm et al., 2009). Comparing to DGS, DDGS has lower cellulose but higher protein and nutritive concentration (Table 1). It has been recognized that DDGS is a good source of vitamins, protein, energy and linoleic acid for feeding (El-Hack et al., 2015, 2017).

Cultivating microorganisms in DGS and DDGS with fermentation can produce microbial fermented feeds (MFF) can expand the feed value, nutrient bioavailability and reduce anti-nutritional factors in DGS (Huang et al., 2020). Microorganisms transform nitrogen and remained alcohol from DGS to bacterial protein and amino acids. In particular, cellulose in DGS can be decomposed by microorganisms to improve the palatability of feeds.

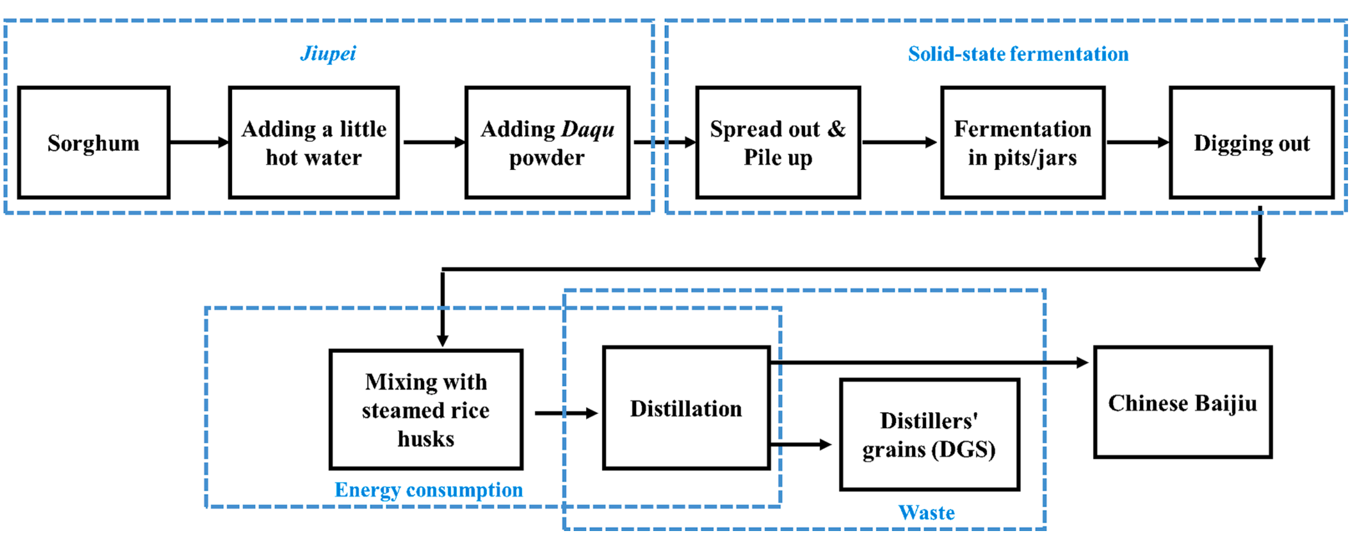


Fig. 1. Chinese Baijiu production process.

2.1.1. DGS and DDGS for livestock breeding

Body weight, meat quality, milk production and quality are important indexes to evaluate the growth performance of livestock. Some studies reported that comparing with CK groups, livestock intake DGS and DDGS feeds (15–45% in diet feeds) had similar growth performance in daily body weight increase and carcass weight (Al-Suwaiegh et al., 2002; Shee et al., 2016). In addition, some researchers reported that the meat quality can be affected by DDGS intake (Beretta et al., 2020; Xie et al., 2016). Beretta et al. (2020) reported that steers backfat thickness drop from 10.2 mm (no DDGS feed group) to 7.3 mm (45% DDGS feed group).

Milk production and quality also can be affected by DGS and DDGS feeds intake. Randby et al. (1999) found that milk production fell from 26.9 to 26.5 kg/day with increased alcohol concentration (0–0.4 g/kg) in feeds. The result indicated that the percent of wet DGS (with remained alcohol) in daily feeds should be controlled. Some studies took similar results and founded that milk fat concentration was affected by dietary treatment significantly (Al-Suwaiegh et al., 2002; Gaillard et al., 2017).

2.1.2. MFF feeding

There were some microorganisms have been wildly applied in MFF, such as *Lactobacillus, Bacillus* and *Aspergillus* (Huang et al., 2020; Sugiharto and Ranjitkar, 2019). Some characteristics of these microorganisms include high-efficiency enzyme production, nontoxic, high protein content in the cell, fast reproduction speed, and no obvious antagonistic relationship with other beneficial bacteria (Sugiharto and Ranjitkar, 2019). Microorganisms fermentation enriches the nutrient components (crude protein, vitamin and total amino acid) in MFF (Wang et al., 2015). For example, (Liang et al., 2001) optimized the production conditions in MFF, which initial pH of 6.5, temperature of 28–32 °C, water content 50–60%, 5% complex microbial inoculants (*Trichoderma ignorum, Geotrichum candidium* and *Candida* sp.). After 40–50 h fermentation period the content of crude protein and vitamin B_2 rose from 16.8% and 13.7 mg/100 g to 27.5% and 48.6 mg/100 g, respectively.

Table 1
Component content and nutrients level of DGS, and DDGS[a] (Al-Suwaiegh et al., 2002; Cromwell et al., 1993; Johnston and Moreau, 2017; Xie et al., 2016).

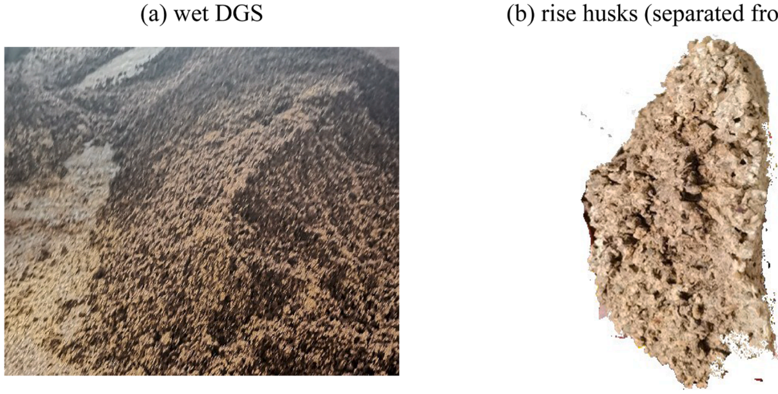
Items	DGS	DDGS
DM%	88.70–89.40	90.31–91.40
Crude Protein%	16.75–27.50	30.30–32.90
ADF%	28.40–45.93	unknow
NDF%	45.80–53.43	unknow
Crude Fiber%	17.12–28.57 [b]	6.40–15.60[b]
Crude Fat%	5.10–10.50	9.00–12.50
C/N	9.60–20.00	unknow
Tannin (mg/kg)	125.09–137.78	unknow
His%	0.24–0.44	0.68–0.89
Ile%	0.56–0.66	1.31–1.64
Leu%	1.20–1.91	4.02–4.37
Lys%	0.33–0.69	0.66–0.69
Phe%	0.59–0.91	1.62–1.78
Arg%	0.52–0.72	0.44–1.09
Met%	0.11–0.28	0.17–0.35
Thr%	0.43–0.72	0.51–1.13
Val%	0.79–0.97	0.82–1.77
Fe (mg/kg)	1247.31–1541.93	2880.00–4220.00
Cu (mg/kg)	19.75–29.28	18.00–19.00
Mn (mg/kg)	181.81–226.69	174.00–238.00
Zn (mg/kg)	73.47–103.21	35.90–47.20

[a] All data are on a dry matter (DM) basis.
[b] significant concentration variation of crude fiber is due to the different production processes in various Chinese Baijiu categories and different rice husk separation approaches

DGS, Distiller's grains; DDGS, Distillers' dried grains with solubles; ADF, Acid Detergent Fiber; NDF, Neutral Detergent Fiber; C/N, Carbon/Nitrogen ratio.

Livestock and poultry took better growth performance than the conventional feed group (CK group). MFF can improve the body constitution, reproductive capacity and antioxidant capacity of finishing pigs. Wang et al. (2016) fed pigs with YC (DGS containing 4% yeast culture) had higher total superoxide dismutase (T-SOD) activity of

(a) wet DGS (b) rise husks (separated from DGS)



(c) sorghums mixed with rise husks (*Jiupei*) (d) *Daqu*

Fig. 2. Materials for Chinese Baijiu production.

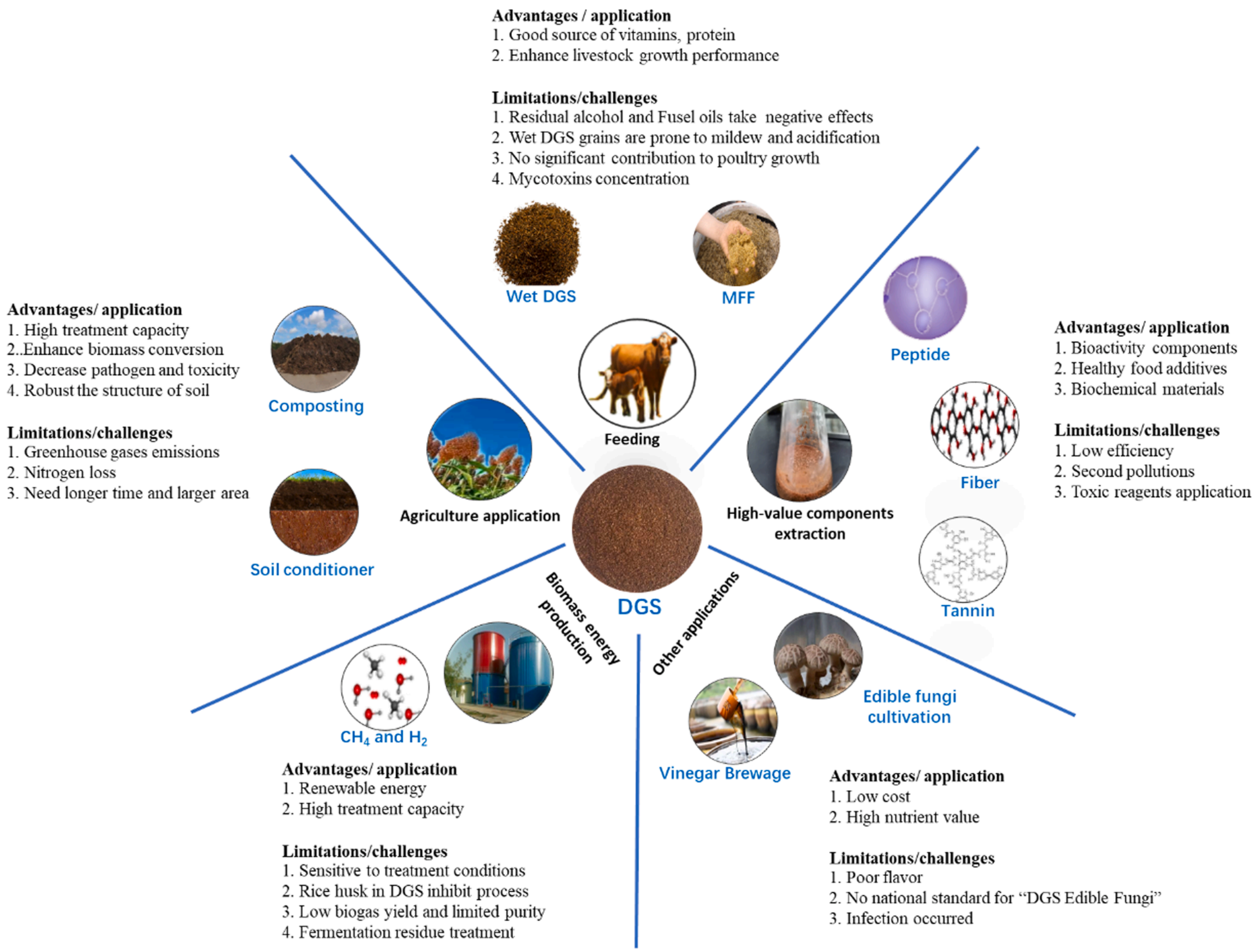


Fig. 3. Chinese Baijiu distiller’s grains (DGS) resourcing. MFF, Microbial fermented feeds.

muscle (rose by 23.58%) and brightness of longissimus dorsi (increased by 2.33%) than CK. Zhang et al. (2018b) fed fattening pigs with MFF (cultivated yeast in DGS) and the results indicated that in the final feeding period (pigs weight over 110 kg), the total protein content of plasma in MFF and CK groups were 79.89 g/L and 70.16 g/L respectively. Meanwhile, the catalase activity in plasma (indicted the antioxidant capacity) enhanced by MFF significantly. At the same time, MFF promoted the growth of poultry well. Wang et al. (2016) feed poultry with YC for higher egg yield. The egg production rate in YC feeding group was higher than CK group science the 8th feeding day, and the promotion was more obvious (up to 4%) in the final period (the 20th day). At the same time, the forming effect of laying hens’ feces was improved, and the eggshell damage rate was significantly reduced.

2.2. High-value component extraction

There are various high-value components in DGS, such as peptide, acids, polyphenol, protein, tannin, yeast extract and dietary fibers (Hu et al., 2020; Villegas-Torres et al., 2015; Zeng et al., 2021). The extracted components can be used in food, biomass membrane, packaging materials, soil conditioners and cosmetics production (Prabhakumari et al., 2018). There are some populated approaches, such as chemical, physical, biological approaches and combined approaches, to improve extraction yield and purity. Common processes for DGS high value components extraction briefly include extraction, purification and identification (Fig. 4) (Das et al., 2020; Jiang et al., 2020a). Physical and enzyme methods can promote the extraction efficiency. After in vitro bioactivity assays, the curb extracts will be filtrated and classified for purification. Finally, the pure extracts take mass spectrometry analysis to identify the molecular structure and components. The bioactivity of pure extracts can be further studied by in vivo assays.

2.2.1. Rice husk separation and dietary fiber extraction

There are some physical approaches have been applied in rice husk separation to decrease the cellulose content of DGS. Applying solid-liquid separator or drum dryer is an effective approach to separate rice husk from DGS (Li, 2004; Yu et al., 2007; Zhou et al., 1992). Rice husks can be discharged with liquid or shaken from dried DGS (Hou et al., 2020). Rice husk separation increases the efficiency in other high-value components extraction. However, both separation approaches declined the content of high-value components in DGS, as the high concentration organic liquid discharge, protein denaturation or overheating issues (Yu et al., 2007; Zhou et al., 1992).

Dietary fibers (DF, includes cellulose, hemicellulose and lignin) contains various vitamins, antioxidants, phenolic compounds is still remain in DGS after rice husk separation and distillation (Li and Komarek, 2017). Soluble dietary fiber (SDF) takes benefits to human health, such as prevent obesity, decline the risk of diabetes and enhance intestinal absorption (Li and Komarek, 2017; Ozyurt and Ötles, 2016). The extracted SDF has been applied in foods and drinks (Cassidy et al.,

Table 2
DGS resource utilization experiment cases.

DGS resourcing methods	Study method	Results	References
Feeds	MMF (DGS with yeast inoculum) for pig breeding	pig daily weight gain, daily feed intake increased by 11.84% and 7.73% respectively. Muscle percent increased 14.03 U/kg	(Wang et al., 2016)
	MMF for cow dairy farming	Milk yield increased by 0.7–1 kg/day, and the milk fat increased by 0.1–0.3%	
	Steers feed with DDGS mixed diet feeds	When the percent of DDGS lower than 13.5%, there were no significant effect on milk production. When the percent of DDDG was 23%, milk production drop by 1.6 kg/day	(Gaillard et al., 2017)
	DDGS mixed diet feeds to Hereford steers	Energy value of DDGS decrease of 24% for 45% inclusion level	(Pancini et al., 2021)
	Mixing DGS (0450 g /kg diet feed) in finishing beef rations over 12 weeks	No significant effect on daily weight grain, but the fat thickness drops by 39.72%	(Beretta et al., 2020)
High value components extraction	Extracted SDF from DGS in alkaline conditions	The extraction rate of SDF higher than 23.6%	(Zhang et al., 2011)
	Extracted protein form DGS in alkaline and acid conditions by Sephadex LH-20 respectively.	Yield of crude protein in alkaline conditions was 7.09% with protein content of 95.2% Yield of crude protein in acid conditions was 3.80% with protein content of 90.09%	(Hou et al., 2020)
	Extracted protein form unmilled DGS with different ethanol	Extracted protein content in 60%, 95% aqueous ethanol were 30% and 35% respectively.	(Cookman and Glatz, 2009)
	Extracted cellulose from corn DGS in alkaline conditions with Glucoamylase and xylanase	Crude cellulose yield was 7.2% with cellulose content of 81%	(Xu et al., 2009)

Table 2 (*continued*)

DGS resourcing methods	Study method	Results	References
	Extracted cellulose form DGS in alkaline conditions with various enzymes (α- amylase, glucoamylase hydrolysis, protease hydrolysis)	Crude cellulose yield was 30.7% with cellulose content of 82.0%	(Yang and Bai, 2019)
	Protein extraction from DGS in urea-cysteine based system and ethanol based system	The maximum protein yield in urea-cysteine based system and ethanol based system were 70% and 50% respectively	(Li et al., 2018)
	Derived six ACE inhibitory peptides from DGS by RP-HPLC	The rang of derived peptides concentration was 0.17–16.96 mg/g	(Wei et al., 2019)
	Extracted 3-deoxyantho-cyanidins from grain sorghum with water stress	Yield increase from 5.2 (without stress) to 245.3 μg/g (with stress)	(Pinheiro et al., 2021)
	Transformed DGS to fermentable sugars by using 2% dilute sulfuric acid treatment at 121 °C	Yield of monomeric sugars was 313 g/ kg DGS	(Zheng et al., 2015)
	Production of surfactin from DGS-water system by microorganism fermentation	Maximum surfactin titration (3.4 g/l) was obtained	(Zhi et al., 2017a)
Biogas production	Mixed DGS and food waste for CH_4 production	Highest average daily production was 28 mL/g/day	(Zhang et al., 2013)
	CH_4 production from sorghum with and without nutrient augmentation (Co and S)	CH_4 yield was 97 mL-CH4/g-VS in not nutrient added groups Yield was 222 mL-CH4/g-VS in nutrient added groups	(Hu et al., 2021)
	H_2 production from DGS-sludge mixed substants	Highest H_2 production rate was 0.17 L/L/d, but high concentration caused longer initial lag phase	(Chuang et al., 2012)
Composting	Co-composting with DGS, bran ash and sludge	At 18th day, the GI of co-composting groups was higher than 80%	(Liu et al., 2020)
	DGS composting with biochar addition	Biochar addition decreased (by half) the N loss, shorten composting period (14 days less) efficiently.	(Wang et al., 2021)
Microorganisms cultivation	Edible fungi cultivation. Cultivating *Lentinus*	The total yield was 320.35 g	(Ren et al., 2018)

(*continued on next page*)

Table 2 (*continued*)

DGS resourcing methods	Study method	Results	References
	edodes in sterilized DGS-sawdust mixed substants	edible fungi / 1000 g DGS	
	Producing reducing sugars from DGS for *Bacillus thuringiensis* cultivation	The spore count for optimized method was 3.8 × 10 ^{8}CFU/mL	(Zheng et al., 2015)
Vinegar Brewage	Brewing vinegar form DGS -corn flour-yeast substants	Acidity was 4.0 g/dL (up to national standard) Special flavor (similar to the Chinese Baijiu flavor)	(Luo et al., 2009)

DGS, Distiller's grains; MMF, Microbial fermented feeds; ACE, Angiotensin converting enzyme; RP-HPLC, Reversed-phase high performance liquid chromatography; VS, Volatile solid.

2018). Studies focused on SDF extraction were widely applied NaOH and enzyme as extraction solution. For example, (Zhang et al., 2012, 2011) extracted SDF from DGS in alkaline (NaOH) and protease conditions respectively. In the alkaline group, the maximum SDF extraction rate was 23.6%, while that in the protease group was 11.7% and took a longer extraction time. On the other hand, insoluble dietary fiber (IDF) has good performance in water and oil retention capacity and cholesterol adsorption capacity (Liu et al., 2021b). It has been applied in functional foods and microorganisms cultivation (as potential source of fermentable sugars) (Liu et al., 2021b; Zheng et al., 2015). However, IDF could decrease the quality on the color, texture and taste in food products (Elleuch et al., 2011). Therefore, some studies focused on the DF modification for higher SDF extraction efficiency (Huang et al., 2021; Ma et al., 2021a).

Some physical approaches, such as steam explosion, ultrasonic and microwave, were applied to break husk structure (Goodman, 2020). High energy, pressure and heat in these approaches affect the surface and inside of the substances and destroy the matrix or cell walls to improve the extraction results (Jiang et al., 2021c). Moczkowska et al. (2019) designed an enzymatic-ultrasonic approach to extract SDF from flaxseed gum, and the highest extraction yield was 17.65%. Ma et al. (2021a) applied steam explosion for wheat bran dietary fiber modification and increased the concentration of SDF from 18.88 to 40.32%. Physical methods with optimized conditions can significantly promote the dietary fiber modification and rose the concentration of SDF in fiber rich materials (Huang et al., 2021; Zhong et al., 2019).

2.2.2. Protein and bioactive peptide extraction

Protein can be extracted both in acid and alkalinity conditions. There are different solvents (include ethanol, isopropanol and, urea-cysteine and aqueous buffer) and enzymes (such as Protex) are applied (Byanju et al., 2020; Cookman and Glatz, 2009; Ioerger et al., 2020; Li et al., 2018). The concentration of CP in DGS is 16.75–27.50% DM, and gliadin takes the dominant status (more than 40% in DGS protein) (Hou et al., 2020). Wang et al. (2009) applied 3 solvents to extracted sorghum protein from DGS. The extraction rate in NaOH-ethanol, acetic acid and HCl-ethanol were 56.8, 44.2 and 24.2% respectively. Cookman and Glatz (2009) founded that higher ethanol concentration (45–90%) did not have a significant effect on protein extraction, but NaOH-45% ethanol (adjusted pH to 8) group had a higher extraction rate (90%). It further showed that the extraction rate was associated with alkaline reagent (pH) more significantly. Furthermore, kafirin (which takes over 60% of total sorghum protein) forms a stable cross-linked structure (Mokrane et al., 2009). Thus, reducing reagents is demanded to decompose the structure. Li et al. (2018) applied urea-cysteine as reducing reagent to enhanced extraction rate and the rate rose by 14–40%.

Bioactive peptides, especially low-molecular-weight (LMW) peptides, with effective functions in antihypertensive, antioxidant properties and antimicrobic (Li et al., 2020). Microorganisms can obtain LMW bioactive peptides by degrading proteins. As a microbial fermentation (by-) production, there were various bioactive peptides in Chinese Baijiu and DGS (Peng et al., 2021). Therefore, DGS can be applied as a source of bioactive peptides. Proteins in DGS can be hydrolyzed by different enzymes to peptides with different molecular weight. After hydrolysis, Sephadex gel chromatography and reversed-phase high-performance liquid chromatography (RP-HPLC) were the important equipment for peptides separation and purification. HPLC with quadrupole-time-of-flight-mass spectrometry/mass spectrometry (HPLC-Q-TOF-MS/MS) were applied to analyze the structure of extracted peptides (Agrawal et al., 2017; Jiang et al., 2021a, 2019). Ethanol, formic acid solution and acetonitrile were the common eluents to extract peptides. Key conditions for peptides extraction include extraction solutions, pH of eluents and temperature. Peptides with different molecular weights and solubility can be separated (extracted) effetely in optimized conditions (Agrawal et al., 2017). Sever bioactive peptides were extracted from DGS. Wei et al. (2019) identified six novel angiotensin-converting enzymes (ACE) inhibitory peptides from DGS prolamins, and the maximum extraction rate was 16.96 mg/g DM. Peng

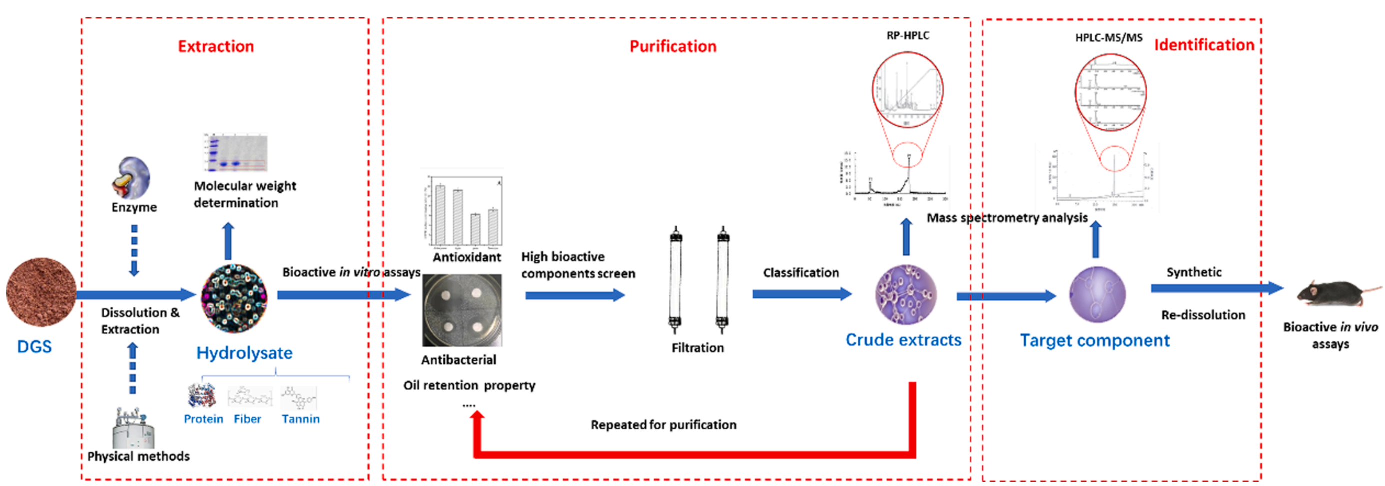


Fig. 4. Processes for high value components extraction. Reversed-phase high performance liquid chromatography, RP-HPLC. High performance liquid chromatography-tandem mass spectrometry, HPLC-MS/MS.

et al. (2021) took in vitro assays to test the bioactive of LMW extracted peptides (< 3 kDa) from DGS. The result indicated that extracted peptides took good performance in antioxidant by efficient NO^- radical scavenging activity. Jiang et al. (2020a) extracted four peptides from DGS and identified antioxidant activity of these peptides by comprehensive chemical and cell-based assays (included ABTS, DPPH, ORAC assay and cell counting kit-8 assay). All of these peptides had certain antioxidant activity in cells, especially for those peptides with lower molecular weight (< 1 kDa). In the further study, one of extracted tetrapeptide (Asp-Arg-Glu-Leu, DREL) by optimized hydrolysis method (yield was 158.24 mg/kg DGS) took in vitro and vivo assays (Jiang et al., 2021a). In the *vivo* assays, researchers investigated the potential activated signaling pathway by DREL and the downstream antioxidant enzymes production. The result showed that damage caused by AAPH (2, 2′-azobis-2-methyl-propanimida-mide dihydrochloride) in the rat liver, heart, and kidneys was alleviated by DREL. High health value of extracted peptides from DGS is remarkable.

2.2.3. Tannin and organic acid extraction

Tannin took good anti-inflammatory, antioxidants and antibacterial properties (Pizzi, 2021). Sorghum is rich in tannin. The concentration of tannin in DGS is 125.09–137.78 mg/kg DM (Das et al., 2020). The bioactivity of tannins include high antioxidant activity, anti-cancer and anti-inflammatory (Palacios et al., 2021). For breading industry, feeds with low concentration tannin enhanced livestock growth (Huang et al., 2018). When dietary tannin concentrations higher than 6% DM, voluntary feed intake, digestive efficiency and livestock productivity were declined. However, when dietary tannin concentrations higher than 6% DM, voluntary feed intake, digestive efficiency and livestock productivity were decreased. Long et al. (2018) reported similar results with low-tannin sorghum diet-fed which declined the body weight of pig. These could because of that low concentration tannin inhibit the activity of pathogen, but higher concentration tannin combinates organic and inhibits the nutrient hydrolysis and absorption in livestock. On the other hand, Halvorson and Gonzalez (2008) investigated that the amount of soluble soil carbon (WSC) and -nitrogen (WSN) in soil drop significant after tannin solution was mixed. This result showed that tannin could undermine the carbon and nitrogen transformation.

Therefore, extracting tannin from DGS could be an effective approach to diminish the negative factors in DGS feeding and composting. There were various approaches for tannin extraction. Hot water (over 80 °C) with different solvents (such as methanol, ethanol, methylethylketone and NaOH) can degrade the cell wall and cause pore formation effectively (Caprarulo et al., 2021; Das et al., 2020). In the sorghum tannin septation and extraction process, Soxhlet extractors, rotary evaporator and freeze drying machine were applied (Das et al., 2020; Rhazi et al., 2019). In addition, some physical approaches, such as microwave, water stress boost the tannin extraction efficiently (Pinheiro et al., 2021; Rhazi et al., 2019). Extracted tannin can be applied in biochemical, medical and food production. Emmambux et al. (2004) added sorghum tannin in sorghum gliadin film production, which enhance the tensile properties of the film. Tannin even as food additives was added into beer to maintain the required taste (Pizzi, 2021).

There are various organic acids in DGS, such as lactic acid, acetic acid, citric acid, hexanoic acid and succinic acid (Zhi et al., 2017b; Zhou and Zheng, 2013). Bioactivity and chemical characteristic of these acids have been approved in different food and material products (Gadkari et al., 2021; Zhou et al., 2019). Existed extraction approaches in for these components from different food wastes can be applied for DGS treatments. For example, Ma et al. (2021b) produced lactic acid from (canteen) food waste by co-fermentation with *Aspergillus niger* cellulase. As a result, lactic acid concentration increased by 22.97% in optimized conditions. It should be noticed that, *Aspergillus niger* cellulase as an important microorganisms in fermentation can improve the yield and flavor of Chinese Baijiu production (Sakandar et al., 2020). Therefore, cellulase can be cultivation from DGS directly. The efficiency of extracted acids can be further improved by DGS fermentation and enzymatic hydrolysis. Zhou and Zheng (2013) inoculated *Actinobacillus succinogens* and mixed yeast extract into enzymatic hydrolyzed DGS (a-Amylase and glucoamylase at pH 6.5). The yield of succinic acid and acetic acid were 19.7 g/100 g DGS and 9 g/100 g DGS at the end of fermentation. Thus, the extracted organic acid from DGS have good potential in product applications.

2.3. Biogas production

Growing population and industrialization increase the energy demand (Akia et al., 2014). To overcome numerous issues related to fossil fuels, biomass energy is a potential option (Ladole et al., 2017). Organic solid waste anaerobic fermentation for methane (CH_4) and hydrogen (H_2) production creates high energy value for DGS utilization (Sekoai et al., 2019; Subramaniam and Masron, 2021). In a research study, (Fu et al., 2014) identified and evaluated the potential of DGS for biogas production, and the amount of biogas produced by DGS (434.2–607.4 mL/g VS) was much higher than that produced by cassava fuel bioethanol stillage (122.3 mL/g VS). Moreover, DGS is a valuable source of organic compounds for H_2 production (Sargsyan et al., 2016; Srivastava et al., 2020). Kuichou Maotai Group (Chinese Baijiu industry giant) applied mesophilic fermentation technology in DGS treatment to produce biogas. The capacity of daily treatment is 300 t DGS, and the maximum biogas yield can achieve 30000 m^3/day. DGS is an ideal substance for biogas production in fermentation.

2.3.1. CH_4 production

Processes of DGS macromolecular transformation in anaerobic methanogenesis are successive. Macromolecular is hydrolyzed into small molecule and absorbed and distributed by microbiologic (*Methanothermobacter*) to transform into simpler compounds (organic acids, volatile fatty acid) which are finally decomposed by methanogenic bacteria to produce CH_4 (Lee et al., 2010). There are some important factors that affect the process of CH_4 production, such as temperature, organic loading rates (OLR) and pH. All of these factors are associated with the accumulation of volatile fatty acid (VFA) which inhibited the process of CH_4 (Eryildiz et al., 2020; Jiang et al., 2012). Increasing temperature can shorten the reaction time and reduce the activity of pathogens (Deng et al., 2016; Jiang et al., 2020b). Kazimierowicz et al. (2021) reported that the average CH_4 production rate of mesophilic (37 °C) system was 2.1–2.8 times higher than that of thermophilic (55 °C) system. Meanwhile, CH_4 production variated with increased OLR. Wang et al. (2014a) fermented food waste with variated OLR. CH_4 production reached the maximum value of 507.58 cm^3/g VS (volatile solids) when OLR was 2.50 kg/dm^3/day. However, with the increased OLR, acid substances (VFA) accumulated and pH decreased, the process of fermentation was inhibited, thus CH_4 production was undermined. Therefore, in order to prevent fermentation failure, OLR was generally controlled between 1 and 4.5 kg VS/m^3/day in fermentation system (Kazimierowicz et al., 2021; Kleyböcker et al., 2012; Wu et al., 2010).

To achieve higher CH_4 production in the anaerobic treatment of DGS the reaction conditions should be optimized. Zhang et al. (2013) mixed DGS and food wastes in fermentation experiment, in the condition of 37 ^oC, total solid content of mixed material at 25% with 50 days fermentation durations, the total gas production rate reached 238.48 mL/g. Johnston and Moreau (2017) inculcated protease to consume the VFA in DGS fermentation, which promoted the CH_4 production by 1–2%. Hu et al. (2021) reported that cobalt effectively improved the removal rate of VFA, and the pH of the system can be controlled at 7–7.2, thus the yield of CH_4 rose from 100 to 223 ml CH_4/g VS.

2.3.2. Biohydrogen production

Fermentation (especially of dark fermentation) is one of the promising biological routes to convert organic solid wastes into biohydrogen (H_2) energy (Ren et al., 2004). Anaerobic acidification bacteria use macromolecular organics (such as cellulose) as H_2 production substrate. The reaction pathways for H_2 production in dark fermentation include pyruvate decarboxylation, formate cleavage and NADH/NAD$^+$balance in microbial metabolize (Islam et al., 2017; Ren et al., 2004). Similar to CH_4 production, H_2 production can be enhanced by optimizing operating parameters, such as food to microorganisms (F/M) ratio, culture temperature and pH (Gioannis et al., 2013).

As containing various available substrates (organic acids and amino acids), DGS is an ideal substrate for biohydrogen fermentation (Sargsyan et al., 2016). Chuang et al. (2012) studied the optimal conditions of H_2 production in DGS and cow feces mixed system. According to the result, when the content of DGS was 80 g/L, 50 °C and pH 6, the yield of H_2 reached the maximum level of 0.40 mmol H_2/g COD. Rorke and Gueguim Kana (2016) used HCl in waste sorghum fermentation (to promote the recovery of xylose), and the H_2 yield achieved at 213.14 ml/g. Sargsyan et al. (2016) found out that culturing bacteria can enhance the H_2 yield in DGS fermentation. The H_2 yield in bacteria cultured group was 1.5–3-folds higher than that in no bacteria group.

2.4. Composting

Composting is an effective technique in organic solid wastes utilization (Negi et al., 2020; Rehman and Qayyum, 2020). Composting can enhance the mineralization and humification of organic matter in DGS and maximize the material cycle. In the duration of composting, organic matter is decomposed by microorganisms into nutrients, such as nitrogen, phosphorus and potassium, and form humus finally. The compost products can be applied in agriculture as fertilizers and soil improvers (Chia et al., 2020; Lal et al., 2015).

2.4.1. Stages of composting

There are three successive stages in composting, which in order are mesophilic, thermophilic and maturity phase (Ezugworie et al., 2021). The soluble and easy degradable organic matters are metabolized by microorganisms initially, which takes active microorganisms' growth. Macromolecular substances (include cellulose and protein) are decomposed by thermophilic microorganisms to form humus acid (Xi et al., 2015). Normally, thermophilic period sustain more than 5 days and temperature stable over 50 °C (Ajmal et al., 2021). Composting with low temperature and short thermophilic period cannot reduce pathogen efficiently (Chang et al., 2021). Subsequently, due to the organic matter decreasing and high temperature, microbial activity is inhibited, thus temperature of the pile decrease. Thermophilic phase followed by maturity phase. When the temperature decreased, the mesophilic microorganisms recapture the dominant status, and further decompose the remained organism in maturity phase to make humus acid becomes more stable (Ezugworie et al., 2021).

2.4.2. DGS composting

Composting can adjust acidity of pile and improve the concentration of humus in substance, and the compost products can be applied in agriculture as fertilizer (Shan et al., 2021). There are many Chinese researchers focusing on DGS composting. It should be noticed that, wet DGS with low pH, could promote phytotoxic effects (remained phenols and heavy metal, Table 1) to inhibit the seeds germination (Moldes et al., 2008). Thus, DGS cannot be treated by landfill directly. Wang et al. (2014b) designed some DGS composting experiments to evaluate the DGS composting product value and optimize the composting conditions. The initial conditions of the simple wet DGS composting were C/N 17, pH 3.6, water content 56.8%, organic matter 87.9%. During the composting, the temperature of pile rose to 50 °C in 6 days, the highest temperature was 62 °C, the high temperature period ($>$ 50 °C) lasted 16 days, and the pH after composting was 6.2. However, the humus index (*HI*, a maturity evaluation index. High quality products have higher *HI*) after composting was 0.52, which indicated the limited agriculture value of simple wet DGS compost products. In order to promote the efficiency of DGS composting and increase the value of products, pile pretreatment and co-composting (mixed materials) are needed (Bustamante et al., 2008).

Microbial inoculum adding into the pile can promote the DGS composting (Wang et al., 2017b), since inoculation can rich beneficial microbial population and produce various desired enzymes to enhance biomass conversion, such as cellulose degradation and organic ammoniation (Chen et al., 2019). Microbial inoculum were cultured from the DGS (Wang et al., 2015, 2014b) or selected those acclimatized bacteria seeds from other resource (sludges or food wastes) (Huang and Shao, 2009). Microbial inoculum includes *Bacillus licheniformis* and *Aspergillus fumigatus* cultured by (Wang et al., 2014b) had good performance in ammoniation and cellulose degradation. After adding inoculum, temperature of DGS pile rose rapidly, achieved high temperature in 4 days (2 days earlier than simple DGS pile), and extended the period of the thermophilic phase. Thus, compost products takes higher nutrients. The content of nitrate nitrogen and total nitrogen rose by 8.5% and 7.3% respectively, the nitrogen loss rate drop by 4.2%, the cellulose degradation rate and extractable humus content increased by 18.7%, and 1.3% respectively and the *HI* rose to 1.11. Furthermore, there were various organic solid wastes have been mixed with DGS in composting to enrich the organic compositions and acculturate microorganisms in pile. Liu et al. (2020) mixed chaff ash, excess sludges and DGS in co-composting. Comparing with simple DGS compost product, the amount of total nitrogen, total phosphorus and total potassium in the co-compost products increased by 7.87%, 10.8% and 10.31% respectively.

DGS compost products enhanced crop and plant growth and took good performance in soil amelioration. Lu et al. (2013) applied DGS compost as fertilizer in sorghum planting and analysis the soil variation. The result showed that, comparing with common fertilizer group the soil microbial in DGS compost group had an enrichment in all sorghum growth stages (such as 50.1% higher for bacteria, 27.1% higher for fungi at sorghum heading stage), and sorghum yield increase by 48.4%. Meanwhile, DGS compost products improve soil conditions efficiently (Hazbavi and Sadeghi, 2016). Huang and Shao (2009) observed that DGS compost products dropped soil pH from 8.3 to 7.4, and rose the contents of total nitrogen, total phosphorus and total potassium in soil by 35.9%, 23.7% and 30.8% respectively. Therefore, more nutrient in soil can be supplied for crop planting, and plant root absorption can be enhanced by compost products (Canellas and Olivares, 2014; Monda et al., 2017).

3. Challenges and future prospect

3.1. Challenges in existing approaches and techniques

There are some challenges in existed DGS approaches. DGS (also include MMF and DDGS) feeds has been accepted in many companies, but the value for DGS utilization is limited (which has been noticed before) and potential health risk should be noticed. High-value extraction increase the products value, but the treatment efficiency is limited. Fermentation and composting, have high capability in DGS treatment, but the efficiency in DGS high-value component resourcing should be enhanced. Second environmental pollutions and greenhouse gas emission also should be noticed in the process of high value components extraction and composting.

3.1.1. Challenges in feeding and MFF production

Pre-treatment should be noticed before DGS application. Poor storage management and drying treatment lost the nutrients in DGS significantly. Wet DGS (pH 3–4.5) are prone to mildew and acidification, especially after long distant transportation and poor storage management. Livestock took deteriorated DGS could cause excitement, dyspnea, red urine, diarrhea and other poisoning phenomena. Meanwhile, residual alcohol, aldehydes and fusels in wet DGS took negative effects on livestock growth. Low concentration of alcohol in feeds ($\leq$ 14.2 g/kg) made a burden on rumen metabolism (Kristensen et al., 2007). The alcohol concentration in rumen blood rose significantly, and the alcohol concentration continued to increase for 5 h. The cows were sedated after eating wet DGS, and the alcohol content of milk was 0.05 g/kg (Kristensen et al., 2007; Randby et al., 1999). Therefore, DGS drying is required, even with the amount of amino acid loss (Lyberg et al., 2013; Stein and Shurson, 2009). In addition, negative effects could also associate with the toxicity of higher alcohols remained in wet DGS (such as soamyl alcohol, amyl alcohol, isobutanol and propanol). Due to the yeast metabolism, higher alcohols are produced in ethanol fermentation (Liu et al., 2021a). Most of higher alcohols have higher boiling temperature than ethanol and water, which means higher alcohols can still remain in DGS and DDGS after drying. Higher alcohols cause metabolic disorder, liver diseases and brain damage (Lachenmeier et al., 2008). The effect of low concentration of higher alcohols in combination with high DGS intake in livestock and poultry should be further studied.

In addition, lower starch and energy concentration in DDGS (in comparison to soybean meal feeds) cause application limitation (May et al., 2010). Some researchers argued that DDGS does not make significant contributions to livestock growth and milk production, even triggered negative effects. Beretta et al. (2020) pointed out that higher percentage of DDGS in diet (up to 450 g DDGS/kg diet feeds) did not take a significant effect on steers growth performances, but inhibited steers' intake activity. Similar result was indicated by (Pancini et al., 2021). When DDGS took high percent (45%) in diet feeds, the gain efficiency reduced significantly (drop 17%). Decreased digestibility of cooked cereals also limited the nutrient intake. The digestible protein content of sorghum and corn fell from 80.8% and 83.4% to 56.3% and 79.3% respectively after cooking (Hamaker et al., 1987). The lower starch, energy concentration and decreased digestibility drop the nutritional value of DGS and DDGS in livestock breeding.

DDGS did not take remarkable promotion in poultry growth. DGS with high fiber content took undesirable components (such as beta-glucans and arabinoxylans) into the intestine slow down the rate of digestion and absorption of nutrient in DGS, and thus reduces the growth performance of animals (especially of monogastric animals, such as chuck and chicken). Barekatain et al. (2013) pointed out that DDGS feeds can enhance chicken body weight increases. However, breeding with high content DDGSS feeds (> 300 g/kg diet) decreased nutrient absorption rate (due to the increased cellulose) and decreased the body fat content. Xie et al. (2016) found that the lower muscle percentage of China micro duck in higher DDGS intake group. However, there was no significant variation in body weight, whole net carcass yield and breast muscle percentage. Meanwhile, DDGS feeds did not have a significant effect on the gee growth performance, meat yield, meat quality or egg production (Damasceno et al., 2020a, 2020b; Wang et al., 2018).

Furthermore, due to the concentration of mycotoxins in raw material, daily intake of DDGS and DGS feed must be controlled (Wu and Munkvold, 2008). The mycotoxins concentration in DDGS post potential risk to livestock and poultry. The degradation of mycotoxins is limited in the fermentation and distillation, which causes the concentration of mycotoxins in DDGS even much higher than that in raw materials (sorghum and rice husk) (Alberts et al., 2020). Mycotoxins cause decreased weight gain, reduced egg production immunosuppression, liver and kidney damage (Dzuman et al., 2016).

On the other hand, there are some problems in the production and application of MFF. High fiber contents in raw material still limits the application. Fermentation need microorganism to product high activity cellulase, which take high requirements in microorganism selection and cultivation. In addition, some factor limited the MFF application 1) high concentration non-starch polysaccharides inhibits other nutrient abortion, 2) remained heavy metal inhibit the nutrient absorption and 3) essential nutrients loss in drying and fermentation (Barekatain et al., 2013, 2014; Beretta et al., 2020). Even though existed studies has reported the national metrics improvement by MFF, the reasons of livestock and poultry growth performances variation are largely unknown. Comprehensive monitor and research in livestock and poultry are still needed (DiGiacomo and Leury, 2019; Sugiharto and Ranjitkar, 2019).

3.1.2. Challenges in high-value component extraction

The extracted components have been applied as raw materials in different productions such as bread, feeds and meat. The incorporation of extracted high-value components into other products might supply additional nutritional benefits to the consumer or livestock and offer an opportunity to decrease the production cost (as the cheap raw material) (Eim et al., 2008; Mildner-Szkudlarz et al., 2013). On the other hand, there were some issues in existed extraction approaches 1) even though rice husk separation can enhance the efficiency of followed extraction, it still decreases the amount of high-value component in DGS. 2) Components denaturation takes higher requirement in the reagents efficiency to interruption of non-covalent interactions. For example, protein denaturation during distillation and drying in DGS treatment makes difficulties in sorghum proteins extraction. Interaction between protein molecules could be stronger in ethanol and decrease the efficiency of hydrolysis (Li et al., 2018).Even though stronger alkali conditions can raise the protein extraction rate, peptide backbones of extracted proteins could be damaged and inferior properties of proteins (Anderson et al., 2012; Li et al., 2018). Moreover, high efficient reagents (especially for those toxic reagents) caused toxic and high pollutant wastes which leaded environmental pollution (Das et al., 2020; Nandi and Guha, 2018). For instance, dimethylformamide as an efficient extraction solution for tannin determination has high toxicity. Discharged water after peptide purification contain acid and polysaccharide can cause second environmental pollutions. 3) Low extraction efficiency and cumbersome processes with high reagents (extraction solutions) and energy consumption (such as ultrasonic and microwave techniques) inhibited the application. There were some researchers focused on peptides precipitation for analysis and extraction. Solvents in these approaches, include water, acetonitrile, methanol, ethanol and acetone, took good performance in LMW peptides (especially 2.5–10 kDa) isolation and analysis. However, amount of solvent for samples dissolution (1:5–200 folds volumes) could cause large discharge waste after extraction and rotary steam (Kawashima et al., 2010; Kinoshita et al., 2000). Meanwhile, conformations of solute molecules are influenced by the solvents, such as alcohol induces peptides to form α-helix structures (Kinoshita et al., 2000), which means that the bioactivity of target peptides could be variated in extraction process (and cause "target lost"). Furthermore, as various incomplete decomposition components in DGS, single enzyme applied in protein extortion processes took low efficiency. Combination reagents (amylase, glucoamylase and protease) were needed to hydrolysis and remove fat, starch glucose in DGS for extraction purification (Jiang et al., 2021a). 4) The ratio of extraction components in products still have up limitation (higher ratio cause poor sensory quality or longer fermentation period), which also undermined the application (Eim et al., 2008). Fiber-enrichments, for example, change the water capacity and sensorial properties of products (Elleuch et al., 2011). These variations affect the quality of products significantly.

3.1.3. Challenges in DGS biogas production

There were some problems in DGS biogas production. 1) Rice husk and cellulose in DGS inhibit the fermentation process. Various intermediate metabolites in the degradation of lignin and callouses, such as VFA and furan derivatives, inhibit the production of CH_4 and H_2 and cause odor issues (H_2S). Sulfide in wet DGS can be hydrolyzed in anaerobic conditions efficiently. May et al. (2010) reported that increased hydrogen sulfide production with increasing wet DGS. It caused higher H_2S emission (rose by 31.48%). 2) Even though there were different pretreatment approaches to enhance H_2 production, the efficiency of biogas production was still limited by the concentration of enzyme and nutrient supplying, which made higher requirements in pretreatment (to maximize the enzyme activity) (Sargsyan et al., 2016). 3) Relatively low H_2 yield and purity limited the technology application. The volume of by-product gas (such as CO_2) took 40–70% of the total biogas volume. The content of CO_2 needs to be reduced to promote biogas utilization. Approaches for biogas purification include chemical and physical washing and membrane separation. However, amount of discharge and waste in biogas purification should be treated. Membrane separation took the highest efficiency in CO_2 removal, but the reuse rate and service life of the membrane need to be improved (Koroglu et al., 2019). 4) Residues after DGS fermentation required further treatment. Che et al. (2021) observed that the DGS biogas residue inhibits the tomato seedling. This is because of that more than 90% of DGS biogas residue was rice husk debris, with low bulk density (0.13 g/cm^3) and weak water holding capacity, which is not conducive to irrigation. Thus, the study about the optimized condition, martial pre-and post-treatment and biogas cleaning in DGS fermentation should be further analyzed.

3.1.4. Challenges in DGS composting

Even though composting is an effective and environmentally friendly approach for organic solid waste utilization, there are still some limitations should be noticed. 1) Initial conditions, such as moisture content, initial C/N and pH, should be optimized. Especially, low C/N and pH of DGS take higher requirements in composting. 2) Additional components (such as feces and sludges) are demanded to rich organic substance and microbial population in DGS composting. However, these components might take risks in composting process and compost application. For example, heavy metal (from sludge) in compost products absorbed by the crops and vegetables can cause health risks (Deng et al., 2020). However, alkaline conditions (by mixing fly ash) are conducive to heavy metal passivation, too high pH limits the growth of microorganisms. Which indicated that it is difficult to optimize the composting processes by simple condition variation (Zhang et al., 2018a). 3) Gas (major are NH_3 and N_2O) emissions should be limited. Gas emissions in composting are not only associated with odor problems but also link with greenhouse and acid rain issues (Meng et al., 2017). Meanwhile, NH_3 emissions account more than 70% of total nitrogen losses (Yang et al., 2020). 4) The cost and land demand also should be considered. Waqas et al. (2018) summarized some existed composting techniques. Some techniques, such as the windrow system, take the lowest cost but require longer time and larger area of land. In-vessel composting requires less land and time, but the cost for material and energy is much higher than other composting techniques.

3.2. Future prospect

Technique and approaches summarized before were separated and independent to each other. Therefore, existed technology and methods in different researches should be combined and organized. With the increased efficiency and optimized conditions in successive approaches, the life cycle and value of DGS treatment can be extended. The flow of organized approaches should be designed.

As a prospect, component extraction techniques can be applied before fermentation or composting to make cascade and full utilization of DGS subsequently (Fig. 5). Before the component extraction, remained organic components and microorganic population in DGS can be classified and quantified by ultrafiltration membrane and mass

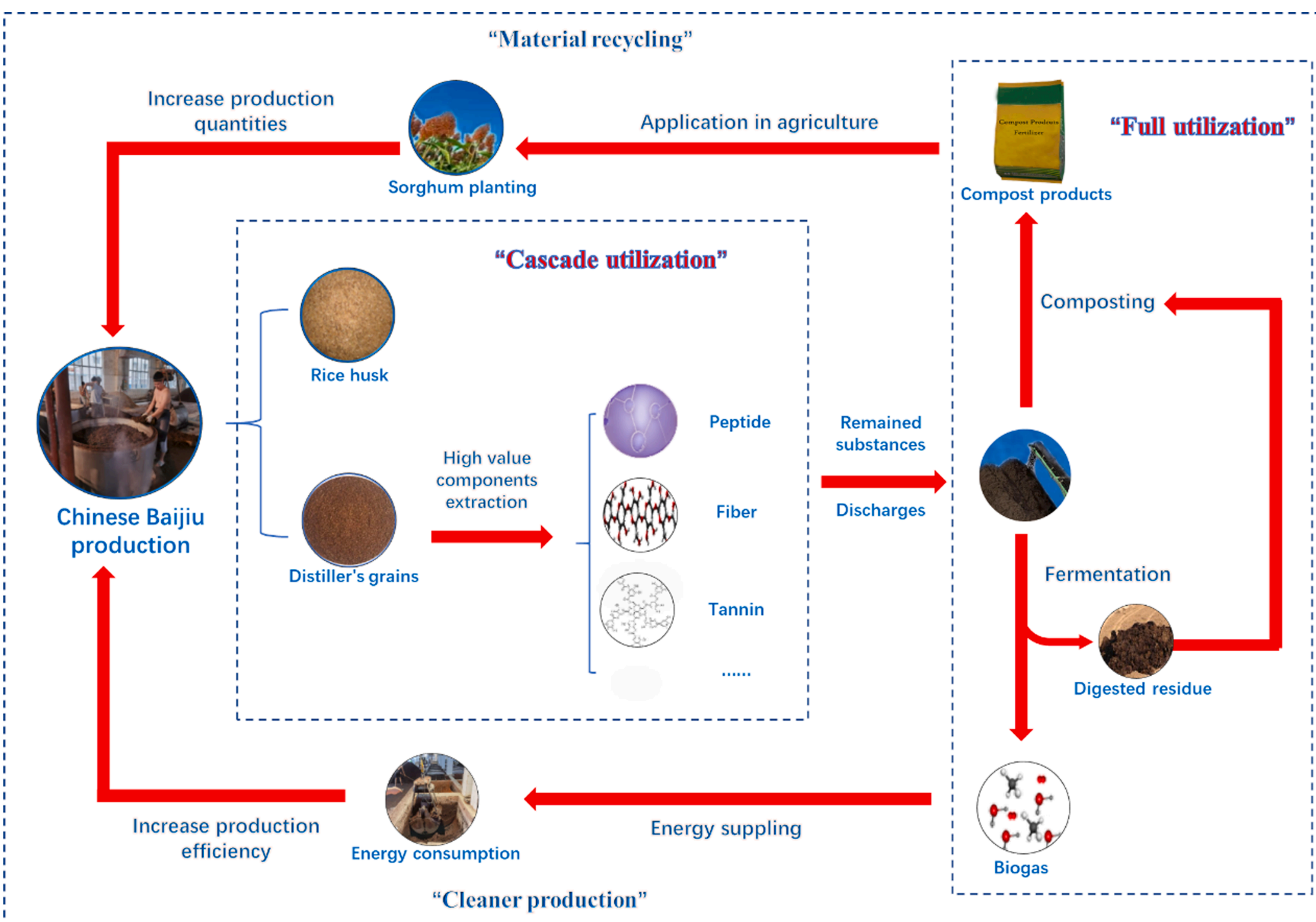


Fig. 5. Processes for cascade and full utilization of Chinese Baijiu distiller's grains (DGS).

spectrometry. According to the result of mass spectrometry analysis, the characteristic and ratio of components in solution can be classified (Jiang et al., 2020a). Meanwhile, the target high-value components (and precursors) can be identified in different solutions. Thus, conditions in extraction processes for different target components (in different solutions) can be optimized at the initial stage. The extracted components can be further applied in other products to make the DGS cascade utilization. For example, the extracted peptides with anti-oxidation bioactivity could take good potential application in Chinese Baijiu production to increase health value (Jiang et al., 2021b). Meanwhile, existed studies reported that the variation in original flavor of Chinese Baijiu after functional peptides adding was not significant (Jiang et al., 2020a, 2021a). The bioactive activity of other components (such as fiber, polysaccharide and polyphenol) extracted from different materials (tea residues and whole-grain cereals) has been reported (Guo and Beta, 2013; Huang et al., 2021). Garzón et al. (2020) reported high intestinal and colonic bio-accessibility (up to 54.9%) of phenolic compounds (concentration was 695.8 ug/g) from novel fermented sorghum food. It indicated that sorghum fermented products or remained substances are potential materials for functional foods production. Thus, extraction and application of these components from DGS should be promoted in further studies, and the approaches and reagents applied in extraction should be low-cost, nontoxic (in case the extracted production as addictive for food and medicine production). Furthermore, the physical and chemical characteristic (such as initial pH, water concentrations, organic concentration) of remained substance can be optimized for later treatments. For instance, fiber modification by steam explosion can enhance organic degradation and enlarge the surface area to absorb odor in further treatment (May et al., 2010; Toledo et al., 2020). Tannin (polyphenol) extraction after fiber modification can have higher extraction rate, as the releasing of fiber combined tannin/ polyphenol (Patle et al., 2020). DGS with lower fiber and tannin concentration could take better performance in composting and biogas production as less inhabitation in microbial growth (which was noticed before).

Subsequently, in the fermentation or composting process, remained substance (extracted-DGS) and discharge can be utilized fully. Wastewater, for instance, can be mixed with extracted-DGS for water concentration adjusting in biogas production or composting. Meanwhile, wastewater in component extraction contains complex polysaccharide, incomplete-hydrolyzed proteins can supply nutrient for microorganism growth (in case amount of organic component loss or separation to solution in extortion steps) (Huo et al., 2020). Other wastes in Chinese Baijiu factories (such as waste *Daqu*, (separated) rice husk, and straw) can be mixed with extracted-DGS. Especially, when DGS biogas production followed by composting, the digested residue can be treated by co-composting (Wang et al., 2017a). The unsterilized and matters can be further degraded. As a result, not only the process of biogas production and composting can be enhanced, but also maximize organic waste recycling. In this way, Chinese Baijiu company can make zero organic solid wastes emission and cleaner production.

4. Conclusion

Various approaches and techniques have been applied in DGS resourcing. It not only provided important reference for the DGS utilization but also took contribution to energy production, agriculture development and environmental protection. Cascade and full utilization can be an effective way to promote DGS utilization. It is suggested that further study for DGS resourcing should focus on the efficiency optimization, processes organization and application promotion for multiplies components extraction and further treatment (for remained substances and discharges). Meanwhile, limitations in each process should be overcome, and a long-term monitory to the effect of product application should be taken.

CRediT authorship contribution statement

Yizhou Liu: Conceptualization, Visualization, Methodology, Validation, Formal analysis, Data curation, Writing – original draft, Writing – review & editing. **Shuangping Liu:** Conceptualization, Visualization, Methodology, Writing – original draft, Writing – review & editing. **Caihong Huang:** Visualization, Methodology, Data curation, Writing – review & editing. **Xiangyang Ge:** Writing – review & editing. **Beidou Xi:** Conceptualization, Data curation, Supervision. **Jian Mao:** Conceptualization, Writing – review & editing, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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