Journal of Food: Microbiology, Safety & Hygiene

OPEN ACCESS Freely available online

Research Article

Forecasting Long-Term Food Grain Demand in China Considering Nexus Effects of Population's Structure, Dietary Structure and Fertility Policies

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ABSTRACT

The population's Age-Gender Structure (AGS) and Dietary Structure (DS) are undergoing rapid changes in China. Moreover, China had further relaxed its family planning policy in 2021. However, few studies have considered these factors simultaneously in forecasting Food Grain Demand (FGD). We established a model to forecast China's annual FGD during 2021-2050, considering the nexus effects of changing AGS, DS, urbanization rate, food waste, etc. The results show that the FGD would peak around 2031 at [319.6, 327.8] million tons with a balanced diet. It might overestimate the FGD by about 2.7-5.2% if AGS was ignored. Interestingly, a relaxing family planning policy has little effect on China's FGD; adopting a balanced diet in China can save about 7.7% of the FGD. In 2050, FGD of urban males and females will account for 43.2% and 40.7% of the total FGD, respectively. Suggestions that help ensure food security and sustainability were provided.

Keywords: Food grain demand; Age-gender structure; Dietary structure; Balanced diet; Food waste

INTRODUCTION

Sustainably meeting global food demands is one of humanity's grand challenges and has attracted considerable attention [1-5], especially when the COVID-19 pandemic hit [6]. It is specially called to forecast the food and feed resources per capita needed to provide a balance diet as a global average in the next half-century [7,8]. Accordingly, here we defined staple food grain and feed grain as food grain. The population's AGS and DS are undergoing rapid changes in China, placing unprecedented demands on food grain [9-11]. Moreover, China has officially further relaxed its family planning policy in 2021, supporting couples that wish to have a third child. Its long-term effects on FGD should be considered. Further, considering the Urban and Rural Structure (URS) of the population and food waste can improve the forecasting accuracy of FGD [4,12,13]. However, at present, a macro estimation that measures the overall China's FGD considering the long-term nexus effects of annual changing AGS, DS, URS of the population, food waste and the latest fertility policy in China is lacking [14-17]. The provision of this information would enable a more accuracy forecasting of the long-term change trend of China's FGD, thus bringing scientific suggestions for improving food grain supply, ensuring food security, and developing appropriate policies to guide birthing plan and residents' diet. In response, we established a multi-factor driven model to forecast China's annual FGD in 3 scenarios from 2021 to 2050 in this paper, with consideration of the nexus effects of changing annual AGS, DS, URS of the population, and food waste in consumption stage. On the one hand, with data of body weight and Physical Activity Level (PAL) of males and females in 12 age groups, we estimated their average daily demand for energy and got their Standard Person Consumption Coefficients (SPCC). With forecasts of population size by age-gender in 3 fertility scenarios, China's annual number of urban and rural standard persons (males or females) were calculated. On the other hand, based on 26 kinds of food consumption structure and their conversion coefficients from kinds of foods to food grain, we estimated the FGD of a standard person who is a male or female in an urban or rural area with a balanced diet or its actual diet. Multiplying with the corresponding size of standard persons, we estimated China's annual FGD from 2021 to 2050 with a balanced diet or actual diet in different fertility policies. To make comparisons, the results with a traditional method in the case that the SPCC was not applied were also calculated.

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Received: 05-Dec-2022, Manuscript No. JFMSH-22-25259; **Editor assigned:** 07-Dec-2022, PreQC No. JFMSH-22-25259 (PQ); **Reviewed:** 21-Dec-2022, QCNo.JFMSH-22-25259; **Revised:** 28-Dec-2022, Manuscript No. JFMSH-22-25259 (R); **Published:** 04-Jan-2022, DOI: 10.35248/2476-2059.22.7.186.

Citation: Liu X, Dou Y (2022) Forecasting Long-Term Food Grain Demand in China Considering Nexus Effects of Population's Structure, Dietary Structure, and Fertility Policies. Food Microbial Saf Hyg. 7:186.

MATERIALS AND METHODS

Figure 1 presents the flowchart of the methodology. Population in different age-gender groups have different nutritional needs. The country's demographic composition will change over time, and so will the population-level nutrient and food demand. Cohort-component method was applied to forecast annual population by age-gender in China in 7 scenarios of different fertility policies from 2021 to 2050 in Liu, et al. [18]. We used the predicted dynamic composition of annual age-gender population in China in the three scenarios from Liu, et al. [18]. Scenario 1 refers to the two-child fertility policy for couples when either the husband or the wife is from a single-child family; scenario 2 corresponds to the two-child policy, and scenario 3 refers to no limitations on the number of children of a couple. China's three-child policy was announced on 1st June 2021 and is expected to maximize the population's role in driving economic and social growth and address the risks of a downward trend in fertility. Liu, et al. [19], indicated that even if the two-child policy is further relaxed, it will exert little influence on fertility choice. It can be supposed that scenario 3 will be most consistent with China's actual population structure and size in the future.

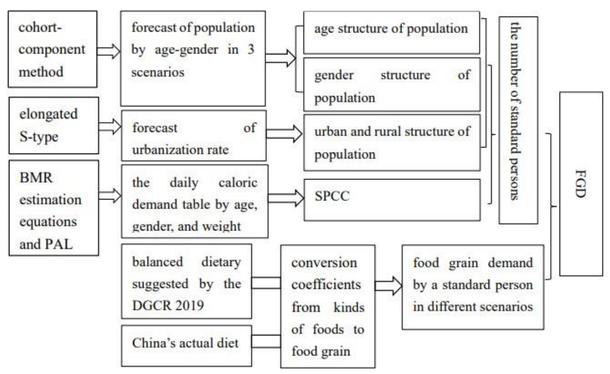

Figure 1: Structural flow diagram for forecasting China's FGD.

The following equations show the details of the model:

$$\alpha_{ik} = BMR_{ik} \times PAL_{ik} \quad \text{........ (1)}$$

$$\delta_{ik} = \alpha_{ik} / \alpha_{17,k} \quad (i=1,2,\ldots 31;\ k=1,2) \text{.......... (2)}$$

$$SP_{iks} = P_{iks} \times \delta_{ik} \quad (s=1,2,\ldots 3;\ i=1,2\ldots 31;\ k=1,2) \text{.......... (3)}$$

$$y = \frac{1}{1+\lambda \times e^{-k\times t}} \quad \text{........ (4)}$$

With equation (4), we got,

$$ln\left(\frac{1}{y}-1\right) = ln\lambda - k \times t \quad \text{........ (5)}$$

Let $ln\lambda = \beta_0$, $-k = \beta_1$, $ln\left(\frac{1}{y}-1\right) = y'$ then equation (5) can be transformed into equation (6).

$$y' = \beta_0 + \beta_1 \times t \quad \text{........ (6)}$$

With China's urbanization rate data during 1978-2020, the linear result obtained by fitting curve is as follows.

$$y' = 1.568 - 0.048\,t + \varepsilon \quad \text{........ (7)}$$

To equation (7), at the significance level of 0.05, R^2=0.99, F=4058.09 and $t_{1.568}$=85.05, $t_{-0.048}$=63.70

$$G_{ij} = \frac{L_{ij} \times V}{1-C_i} \quad (i=1,2,\ldots 9;\ j=1,2,3,4) \text{.......... (8)}$$

$$AG_j = \sum_{i=1}^{9} G_{ij} \times 365/1000 \quad (j=1,2,3,4) \text{.......... (9)}$$

$$sgd_s = \sum_{k=1}^{2}\sum_{i=1}^{6} sp_{iks} \times y \times su_k + \sum_{k=1}^{2}\sum_{i=1}^{6} sp_{iks} \times (1-y) \times sr_k \quad (s=1,2,3;\ k=1,2;\ i=1,2,3,\ldots 6) \text{.. (10)}$$

$$gd_s = u_k \times up_{ks} + r_k \times rp_{ks} \quad (k=1,2;\ s=1,2,3) \text{.......... (11)}$$

$$agd_s = AG_4 \times p_s \quad (s=1,2,3) \text{.......... (12)}$$

We proposed Standard Person Consumption Coefficient (SPCC) to introduce the age-gender structure variable to estimate population-weighted average dietary energy requirements. We estimated Basal Metabolic Rate (BMR) from body weight of males and females in 12 age groups with equations from Henry, [20], in Table 1. The estimated BMR and data of Physical Activity Level (PAL) for 12 age-gender groups were applied to estimate their α_{ik} with equation (1), based on which, we calculated δ_{ik} for Chinese males and females at 31 age groups by equation (2). The results were shown in Figure 2.

Table 1: Equations for estimating BMRfrom body weight.

Age (Years)	BMR_{ik}(MJ/day)
Males	
<3	0.2550*AW_{ik}-0.14
3-9	0.0937*AW_{ik}+2.15
10-17	0.0769*AW_{ik}+2.43
18-29	0.0669*AW_{ik}+2.28
30-60	0.0592*AW_{ik}+2.48
>60	0.0563*AW_{ik}+2.15
Females	
<3	0.2460*AW_{ik}-0.0965
3-9	0.0842*AW_{ik}+2.12
10-17	0.0465*AW_{ik}+3.18
18-29	0.0546*AW_{ik}+2.33
30-60	0.0407*AW_{ik}+2.90
>60	0.0424*AW_{ik}+2.38

Note: *: AW_{ik} is expressed in kg BMR equations in the table were sourced from Henry, [20].

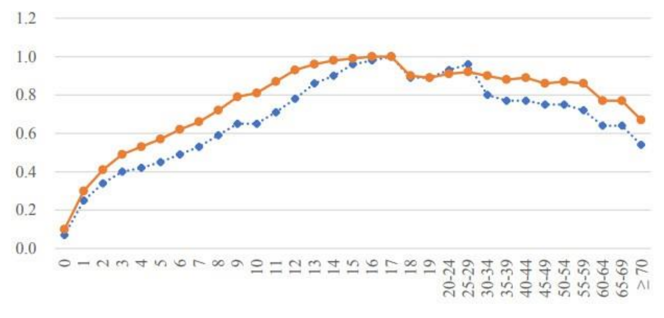

Figure 2: The estimated δ_{ik} for Chinese males and females at 31 age groups. **Note:** ( ) δi1-males, ( ) δi2-females.

With δ_{ik} and the predicted dynamic composition of annual China's population by age-gender, we can get the annual number of standard persons (males or females) at 31 age groups in China from 2021 to 2050 with equation (3). China's urbanization rate had risen steadily every year, from 17.92% in 1978 to 63.89% in 2020. The development of the urbanization rate in various countries indicates that it presents an elongated S-type curve. The urbanization rate increases rapidly after the first inflection point, slowing down obviously after the second inflection point. Based on Japanese and German experiences, China's urbanization process may slow down after reaching 65%-70%; at present, China is still in an accelerated period of urbanization. Elongated S-type function was applied to forecast China's urbanization rate in equations (4-7). Then we can get China's annual number of urban and rural population by age-gender and the corresponding standard persons. The results were shown in Figure 3. The estimated conversion coefficient of livestock products to food grain consumption are shown in Table 2.

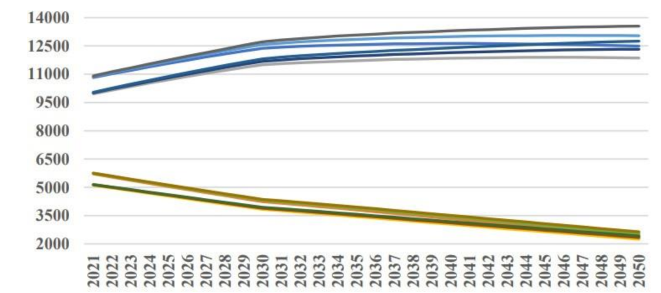

Figure 3: The predicted usgdks and rsgdks (Unit: 10000 tons). **Note:** ( ) usgd11, ( ) rsgd11, ( ) usgd21, ( ) rsgd21, ( ) usgd12, ( ) rsgd12, ( ) usgd22, ( ) rsgd22, ( ) usgd13, ( ) rsgd13, ( ) usgd23, ( ) rsgd23.

Table 2: The grain consumption conversion coefficient of different kinds of livestock products.

Livestock products	The grain consumption conversion coefficients
Pork	2.8
Beef and Mutton	1
Poultry	2
Eggs	1.7
Milk	0.3
Fish	0.9

According to DGCR 2019, the per capita FGD in the balanced dietary pattern is divided into high, medium, and low levels. The average 26 kinds of food consumption structure in China during 2014-2018 were estimated with data from FAOSTAT (2014-2018). The results were shown in Table 3. The estimated conversion coefficients of 9 kinds of foods classified in a balanced diet (V_i) according to Tang, et al. [10], and Chen, et al. [21]. To the food consumption data from FAOSTAT, food waste in household was not accounted for, this will lead to a lower estimation of food grain consumption. We used the percentages of foods waste in household consumption in Southeast Asia as those in China (C_i). V_i and C_i were listed in Table 4. The per capita daily i-th categories of FGD by an adult in low, medium, and high level suggested by DGCR 2019 respectively G_{ij} can be estimated with equation (8) (Table 5). The per capita annual FGD by an adult in low, medium, and high level suggested by DGCR 2019 respectively AGj can be estimated with equation (9). We got AG_1=215.8 kg, AG_2=275.0 kg, AG_3=334.2 kg and AG_4=259.3 kg. We took the high level of the food grain consumption based on the DGCR 2019, AG_3=334.2 kg/year, as the volume of food grain consumption of an urban male standard person with a balanced diet.

Table 3: The average 26 kinds of food grain consumption structure in China during 2014-2018.

Varieties	Food grain items	Average annual food consumption 2014-2018 (1000 tons)	Proportion (%)
Grains	Cereal	271095	81
	(Wheat)	92106	34
	(Rice)	168651	62.2
	(Maize)	10338	3.8
	Pulses	1991	0.6
	Tubers	61748	18.4
Meats	Pig meat, bovine meat, and mutton	66332	75.3
	(Pig meat)	54176	81.7
	(Bovine meat)	7148	10.8
	(Mutton)	5008	7.5
	Poultry	20249	23.4
	Other	1473	1.7
Aquatic products	Crustaceans	6386	13.4
	Freshwater fish	24985	52.4
	Marine fish	2102	4.4
	Molluscs aquatic products	14178	29.8
Milk	Cow milk	32548	88.1
	Other	4380	11.9
Eggs	Chicken egg	23078	84.4
	Other	4251	15.6
Vegetable	Tomato	48379	9.8
	Other	443234	90.2
Fruit	Apple	30574	22
	Other	108375	78
Pulse and nut	Pulse	1991	34.6
	Nut	3756	63.4
Oil	Animal fats	11852	79.8
	Vegetable oils	2996	20.2

Table 4: V_i and the assumed C_i in China.

Foods	V_i	C_i	L_{i1}	L_{i2}	L_{i3}	L_{i4}
Cereal, tubers and beans-1	1	3%	250	325	400	358.7
Vegetable-2	0	7%	300	400	500	260.9
Fruit-3	0	7%	200	300	400	125.4

Fish and shrimp-4	0.9	2%	50	75	100	32.4
Meat and poultry-5	2.3	4%	50	62.5	75	99.5
Eggs-6	1.7	1%	25	37.5	50	27.2
Milk and Dairy-7	0.3	1%	300	300	300	33.4
Pulse and Nut-8	1	1%	30	40	50	11.4
Oil-9	0.15	1%	25	27.5	30	27.8

Table 5: The per capital daily FGD of China's residents (Unit: g).

Items	G_{i1}	G_{i2}	G_{i3}	G_{i4}
Cereal, tubers and beans-1	257.7	335.1	412.4	369.7
Vegetable-2	0	0	0	0
Fruit-3	0	0	0	0
Fish and shrimp-4	45.9	68.9	91.8	29.7
Meat and poultry-5	119.8	149.7	179.7	238.4
Eggs-6	42.9	64.4	85.9	46.7
Milk and Dairy-7	90.9	90.9	90.9	10.1
Pulse and Nut-8	30.3	40.4	50.5	11.5
Oil-9	3.8	4.2	4.5	4.2
Sum	591.3	915.7	753.6	710.5

According to the recommended dietary energy intake for Chinese residents, at age 18-50 years old, it is 11.3 MJ/d for males and 9.6 MJ/d for females [22], which means the dietary energy demand of a female is 85.1% of that for a male on average. Then, the FGD for an urban female standard person was estimated to be 284.4 kg/year. According to Xin, et al. [23], the difference between urban and rural residents' per capita food grain consumption was about 45.7 kg. Therefore, the FGD with the balanced diet of a standard person (male or female) in an urban and rural area can be estimated with equation (10). If the SPCC was not applied, equation (11) was traditionally used to estimate the FGD with a balanced diet. We set $u_1=AG_2$ with the same method to estimate su_k and sr_k, we got the value of u_k and r_k (Table 6). If the actual dietary structure was kept in scenario s, agd_s was estimated with equation (12). Since we considered multiple factors that drive the change of FGD in the forecasting process, we call the model established in this paper the multi-factor driven model. Definitions of all notations are listed in Table 7.

Table 6: The estimated FGD of a standard person or per capita FGD with a balanced diet (Unit: kg/year).

Urban male (su_1)	**Urban female (su_2)**	**Rural male (sr_1)**	**Rural female (sr_2)**
334.2	284.4	288.5	238.7
u_1	u_2	r_1	r_2
275	234	229	188

Table 7: Definitions of all notations.

Notations	**Definitions**
α_{ik}	Average daily demand for energy of a person at the age i with gender k, k=1 means male, k=2 means female
BMR_{ik}	Basal Metabolic Rate of a person at the age i with gender k
PAL_{ik}	Physical Activity Level of a person at the age i with gender k
Aw_{ik}	Average weight of a person at the age i with gender k
δ_{ik}	The standard person consumption coefficient of a person at the age i with gender k
mfr_s	Male to female ratio in scenario s
y	Urbanization rate
y'	Replacement variable of y
t	Time, we set t=0 in 1978, t=1 in 1979, t=2 in 1980, ...
λ, k, Q_0, Q_1	Parameters
L_{ij}	The per capita daily FGD of i-th categories of food based on DGCR 2019 in three level of low (j=1), medium(j=2) and high (j=3)
L_{i4}	Actual average per capita daily foods consumption
V_i	The conversion coefficient of i-th category of food
C_i	The percentage of food waste in household consumption of i-th category of food
G_{ij}	The per capita daily i-th categories of FGD by an adult in low, medium, and high level suggested by DGCR 2019 respectively, (j=1,2,3)
AG_j	The per capita annual FGD by an adult in low, medium, and high level suggested by DGCR 2019 respectively
G_{i4}	The actual average per capita daily i-th categories of food grain consumption
p_{iks}	The size of persons at the age group i with gender k in scenario s
sp_{iks}	The size of standard persons at the age group i with gender k in scenario s
usp_{ks}	The size of standard persons in urban area with gender k in scenario s
rsp_{ks}	The size of standard persons in rural area with gender k in scenario s
sp_{ks}	The size of standard persons with gender k in scenario s
sp_s	The size of standard persons in scenario s
su_k	The estimated FGD of a standard person with gender k in urban area with a balanced diet
sr_k	FGD of a standard person with gender k in rural area with a balanced diet
u_k	Per capita FGD with gender k in urban area with a balanced diet
r_k	Per capita FGD with gender k in rural area with a balanced diet
sgd_s	The FGD with SPCC method in scenario s with a balanced diet
$usgd_s$	The FGD of urban standard persons in scenario s with a balanced diet

$rsgd_s$	The FGD of rural standard persons in scenario s with a balanced diet
$pusgd_{ks}$	The proportion of FGD of urban standard persons with gender k in scenario s with a balanced diet account for sgd_s
$prsgd_{ks}$	The proportion of FGD of rural standard persons with gender k in scenario s with a balanced diet account for sgd_s
$pursgd_s$	$pursgd_s=usgd_s/rsgd_s$
gd_s	FGD with traditional method in scenario s
up_{ks}	The size of urban population with gender k in scenario s
rp_{ks}	The size of rural population with gender k in scenario s
p_s	The population size in scenario s
agd_s	If the actual dietary structure was kept, the FGD in scenario s

Data source

The nutrient requirements are from the DGCR 2019. The value of PAL for different age-gender groups is sourced from FAO, [24], which is the latest reference we can find. According to the data available in the FAO database, the period of 1961 to 2018 is chosen to be studied. Typical diet varies across countries and reflects a country's tradition and culture and natural and land-use conditions. We used the average reported food consumption between 2014 and 2018 (to smooth out fluctuations in any one year) as the baseline for China's typical diet. The weights of males and females aged 0-69 in China are sourced from the 2014 National Physical Fitness Monitoring Bulletin published by the State Sports General Administration. The average weight of Chinese males over 70 years old was 63.5 kg, and of Chinese females was 55.6 kg [25]. 1978-2020 data of the urbanization rate is sourced from National Bureau of Statistics of China. We chose annual time data because it is appropriate for the production cycle and the time scale of the model (2021-2050), and also because data on consumption, production, and population are only available annually.

RESULTS

Predicted size of Chinese standard persons by age-gender

In Figure 4, sp_{k3} is the largest in 3 scenarios. With time going on, the differences among sp_{ks} become more obvious. In 2050, sp_{13} will increase 3.9% over sp_{12}, 8.5% over sp_{11}; sp_{23} will increase 3.5% over sp_{22}, 7.5% over sp_{21}. Mainly because of aging problem of the population (Figure 2), sp_3 is expected to grow to its peak of 1111.8 million in 2030, then goes down to 1105.2 in 2035, 1089.0 in 2040, and 1046.7 in 2050 (Figure 4). The results are accordingly with the predicted p_s. Compared with sp_2, the peak of sp_3 would increase by about 1.3%, and the aging rate (which is the proportion of elderly persons aged ≥ 60 years accounts for the total size of the population) would decrease 0.4 percentage points in 2030, 0.7 percentage points in 2040, and 1.3 percentage points in 2050 in scenario 3 than those in scenario 2. Because of women live longer than men averagely, and their α_{ik} are different, from 2021 to 2050, the predicted mfr_s of Chinese standard persons would decrease from about 0.925 to 0.904 in scenario 3, to 0.901 in scenario 2 and to 0.896 in scenario 1 (Figure 5). Since FGD of a male standard person is different with that of a female standard person, the different trend of mfr_s will impact the total FGD indirectly.

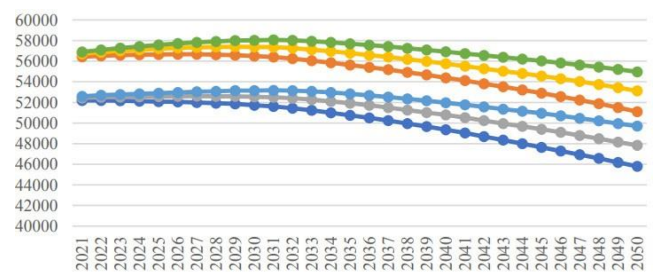

Figure 4: The predicted spks. **Note:** ( ) sp11, ( ) sp21, ( ) sp12, ( ) sp22, ( ) sp13, ( ) sp23.

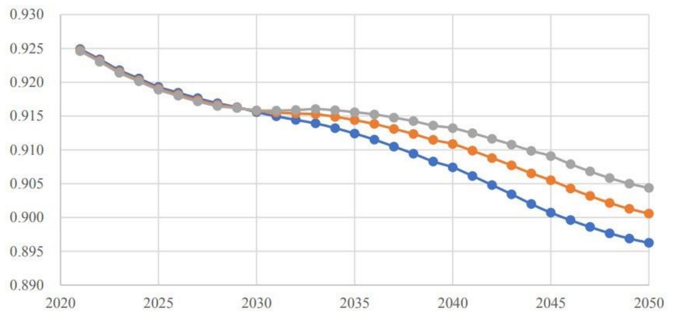

Figure 5: The predicted mfr_s of Chinese standard persons. **Note:** ( ) mfr1, ( ) mfr2, ( ) mfr3.

Predicted urbanization rate and standard persons in urban and rural areas

Here the level of urbanization rate is measured by the proportion of urban permanent population in the total permanent population. It is predicted that China's urbanization rate would be 64.11% in 2021, 73.69% in 2030 and 83.69% in 2050 (Figure 6), which are consistent with the judgment of several studies such as from RDR, [26], and UDE, [27]. Figure 7 shows usp_{ks} would increase year on year. And rsp_{ks} would have a downward trend annually. The gap between them would widen year on year. usp_{23} would be the most in 12 groups during 2021-2050. In 2050, usp_{23} would increase to 448.38 million persons, which is 3.5% higher than usp_{22} and 7.5% more than usp_{21}. Similarly, as more rural residents become urban residents, rsp_{13} would have the smallest value in 2050. Compared with the other two scenarios, rsp_{13} would be 3.9% smaller than rsp_{12} and 8.5% smaller than rsp_{11} in 2050.

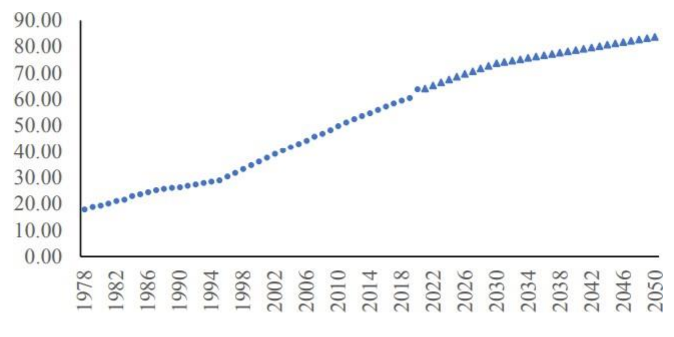

Figure 6: The urbanization rate in China from 1978 to 2050(%).

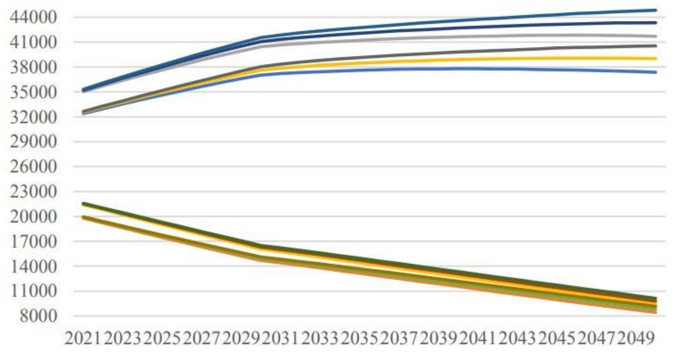

Figure 7: The predicted usp_{ks} and rsp_{ks} (Unit:10000 persons). **Note:** ( )usp11, ( ) rsp11, ( ) usp21, ( ) rsp21, ( ) usp12, ( ) rsp12, ( ) usp22, ( ) rsp22, ( ) usp13, ( ) rsp13, ( ) usp23, ( ) rsp23.

The estimation results of China's FGD and its structure

Figure 8 show that sgd_3 would peak at 328.7 million tons in 2032; gd_3 would peak at 353.2 in 2034, which is 7.4% higher than that of sgd_3. For the three scenarios, the difference between sgd and gd would be in the range of 18.4-34.6 million tons. The lower and upper bounds accounts for 2.7% and 5.2% of China's grain production in 2020 and about 0.7% and 1.2% of world grain production in 2020, respectively. The longer the time, the more considerable difference they have. We may overestimate China's FGD by 2.7-5.2% during 2012-2050 if we ignore the AGS of the population. Thus, it may lead to an oversupply of grain and accumulation of stocks, which will generate additional inventory costs burden of about 0.2-0.3 billion RMB annually. From Figure 8, we know that the value of gd is between sgd and agd each year. In scenario 3, agd_3 is averagely 51.2 million tons greater than sgd_3 during 2021-2050, which means that if all Chinese households adopt DGCR 2019 in scenario 3, about 51.2 million tons of food grain would be saved, which accounts for 7.7% of China's grain production in 2020, accounts for about 1.8% of world grain production in 2020. The results indicate that we should promote DGCR 2019 more popularly since there would be a double dividend – a healthier population and a saving of about 7.7% of China's food grain consumption, reducing the scarcity pressure of water and land [28]. Figure 8 shows in each year, sgd_3 is greater than sgd_2, and sgd_2 is larger than sgd_1 because of different fertility policies. Compared with sgd_2, sgd_3would have increments of 2.1 million tons in 2025, 3.7 million tons in 2030, and 11.2 million tons in 2050. sgd_3 is greater than sgd_1 with increments of 5.1 million tons in 2025, 8.7 million tons in 2030, and 23.4 million tons in 2050, which accounts for 0.8%, 1.3%, and 3.5% of China's grain production in 2020, respectively. China's annual restaurant food waste was about 17-18 million tons in 2015 [12,29]. About 35% of China's grain production was wasted annually around 2014 [30]. It is much higher than the annual increase in FGD due to family planning policy changes over 2021-2050. Hence, the shift in population size and structure caused by China's fertility policy adjustment is not the main factor that will influence China's FGD from 2021 to 2050.

Figure 9 shows that $pusgd_{13}$ accounts for most of sgd_3 in each year during 2021- 2050. It increases gradually from 34.2% in 2021 to 43.2% in 2050. The proportion of $prsdg_{23}$ ranks second in the four classifications in Figure 9. It has a similar trend as $pusdg_{13}$, increasing from 31.5% in 2021 to 40.7% in 2050. $prsdg_{23}$ is the smallest in the four classifications in each year; it has a downward trend, decreasing from 16.2% in 2021 to 7.7% in 2050. $prsdg_{13}$ has a similar change trend with $prsgd_{23}$. $pursgd_3$ would increase from 1.9 in 2021 to 5.2 in 2050. These indicate that urban males would consume more food grain. Cheng, et al. [31], found that in urban restaurants, the average food waste per meal of a male is about 93 g, which is 16% higher than that of a female consumer. The per capita food waste per meal of consumers aged 40-50 is the highest in all age groups in China, reaching 99 g. We should pay much more attention to reduce their food waste in the consumption stage.

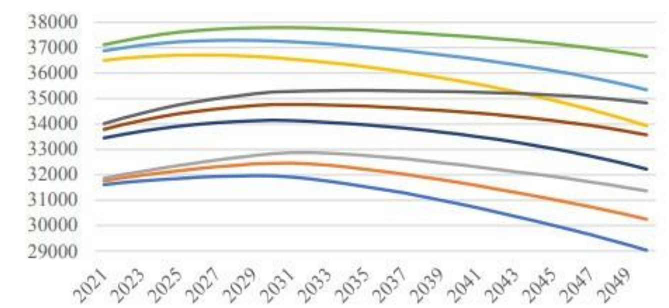

Figure 8: The estimated China's FGD with different methods in the three scenarios (unit: million tons). **Note:** ( )sgd1, ( ) sgd2, ( ) sgd3, ( ) agd1, ( ) agd2, ( ) agd3, ( ) gd1 ( ) gd2, ( ) gd3

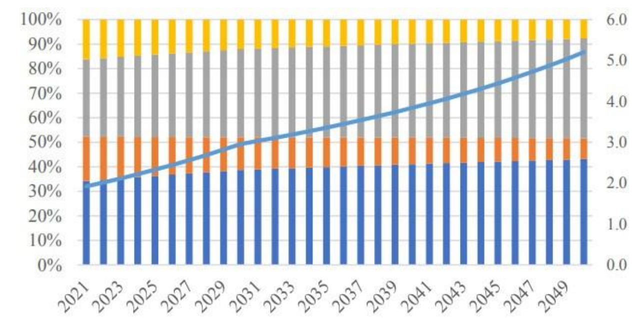

Figure 9: The component structure of sgd_3 from 2021 to 2050. **Note:** ( ) pusgd13, ( ) prsgd13, ( ) pusgd23, ( ) prsgd23, ( ) pursgd3.

Sensitive analysis

A sensitivity analysis is needed to estimate the impact of some uncertainty in the average weight of the population over 70 years; currently, these estimates are 63.5 kg for a male and 55.6 kg for a female [25]. The effect of a 5 kg fluctuation of average weight over 70 years old on FGD is shown in Table 8. In 2030, 2040, and 2050, the proportion of the population over 70 years old would be 11.4%, 17.1%, and 21.3%, respectively. The sensitivity analysis results show that if the fluctuation of average weight over 70 years old is within 5 kg, the impact on FGD is less than 0.8%. Therefore, we can accept the estimation of the average weight over 70 years old in this paper.

Table 8: Effect of average weight fluctuation of people over 70 years old on FGD.

Average weight over 70 years	2021	2025	2030	2035	2040	2045	2050
± 5 kg	0.27%	0.34%	0.39%	0.49%	0.62%	0.72%	0.76%

DISCUSSION

Compared with the traditional forecasting methods for FGD, this study considered the nexus effects of changing AGS, DS, URS, and food waste, etc., in the forecasting model. These factors are common in the actual situation, but their nexus effects are challenging to incorporate into existing models. In addition, the adopted model includes a comprehensive list of 26 kinds of foods and is linked to a balanced diet. The model can thus be used to identify which food may be in short supply to meet a balanced diet under different scenarios. Significantly, the model can be applied to evaluate the impacts of China's family planning policies on FGD, which arouses the intense attention of the government, residents, and academics. Although prices are not explicitly incorporated in this model, the price mechanism to allocate commodities among residents was partially incorporated in the consumption and dietary preferences [32]. There are BMR equations for Chinese people averagely but not for different age groups. Equations for estimating BMR of varying age groups in this paper were derived from Henry, [20], the latest equations we can find for the world population. But they are not designed specially for Chinese. This may bring some uncertainty. We used the percentages of foods waste data in Southeast Asia as the data for China since there have no such detailed data in China. To prevent food waste, China has been formally implemented a law on preventing food waste from April 29, 2021. With the law's effects, food waste in China should be decreased much more than ever in recent years and the future, which means that the value of C_i applied in the forecasting model may be a little bigger than actual, and this may lead to the predicted sgd a bit higher than actual. So far, we have only considered the average food intake for the different age-gender groups in China's urban and rural areas. We have not considered the preference of foods and different constitutions of the population across various regions in China. Further research will need to be conducted to address the spatial heterogeneity within China. In Table 9, L_{i4} was estimated with the average per capita daily food consumption of different categories from 2015 to 2019 sourced from China Statistical Yearbooks. We can see that L_{54} is 1.3 times of L_{53} . L_{14} , L_{94} are in the suggested range (L_{11}, L_{13}) and (L_{91}, L_{93}). While L_{74} is only 0.1 times of L_{71}, L_{84} is 0.4 times of L_{81}. L_{34} L_{44} is 0.6 times of L_{31}, L_{41} respectively. These indicate that Chinese households consumed more meat and poultry, but their consumption of milk and dairy, pulse and nut, fruit, and vegetables was insufficient to accord with DGCR 2019. Table 9 shows some predictions for China's grain demand in 2020 and 2030 in some literature. As their prediction models and parameters differ from each other, it is not surprising that their results are also different [33,34]. Table 9 found that if the population's age structure and URS were considered in the prediction model, the predicted grain demand is usually smaller than those that ignored these factors. The forecasting results of this study show the same rule, which verifies the reliability of our predicted results to a certain extent [38-43].

Table 9: Predicted results of China's grain demand in some literature.

Methods	Predicted year	Population age structure	Urban-rural structure	Predicted China's grain demand (million tons)	References
Time series	2020	No	No	590	[35]
Balanced diet	2020	No	No	567	[10]
Balanced diet	2020	Yes	Yes	480	[36]
Nutrition demand	2020	No	Yes	576	[9]
CEMM	2030	No	Yes	610	[37]
Balanced diet	2030	No	Yes	586	[10]
Balanced diet	2030	Yes	Yes	560	[36]

CONCLUSION

In summary, from the results, we have four main findings and suggestions. (1) The change of AGS, especially the increase of the aging rate, will reduce the FGD and release the pressure on food grain security. Compared with prediction results provided by traditional methods, this paper shows that China has about 2.7-5.2 percentage points of slack space in planning its future FGD during 2021-2050, which can save about 0.2-0.3 billion RMB in grain annual inventory costs. Furthermore, the paper provided the annual demand structure of FGD when it meets the balanced dietary demand. FGD of urban males and females will account for 43.2% and 40.7% in 2050, respectively. The predicted results can be referred to to adjust China's food grain supply structure in the future. (2) The change of population size and structure caused by the adjustment of China's fertility policies is not the main factor influencing China's FGD from 2021 to 2050. This finding can help dispel the worry of food shortage caused by the relaxing of fertility policies. We can promote public policies, such as strengthening China's infrastructure and public facilities to support child-rearing, free universal public schooling from the age of three, improving the average level of compulsory education, etc., to increase fertility rate. (3) Interestingly, our results indicate the implementation of DGCR 2019 can make people healthier and save about 7.7% of food grain consumption. Our research further shows that Chinese people should consume more milk and dairy, pulse and nut, fruit, and vegetables to accord with DGCR 2019. While 72.6% of residents in Henan province of China were not aware of DGCR 2019, 89.6% not aware of the recommended intake of salt, and

96.8% not aware of the recommended intake of edible oil, and the awareness rate of urban areas was higher than that of rural areas revealed that education is a more important influence than income in ensuring dietary balance and nutritional quality. We should strengthen the publicity and promotion of DGCR 2019, especially in rural areas and to middle-aged and elderly groups. Increasing trade always improves the nutrition security of countries. (4) The problem of food waste is prominent in China. An essential reason behind food waste in China is the "mianzi culture." The law on preventing food waste has been formally implemented in China from April 29, 2021. Relevant departments should organize and formulate a series of action plans to advocate green, healthy, and sustainable consumption patterns. We should specially strengthen the publicity and education on saving food for urban males and residents aged 40-50 in China. Though we used China as a case study, it can also be an example for developing countries facing similar challenges, such as India, Bangladesh and Africa.

ACKNOWLEDGMENTS

This work was supported by grants from the National Nature Science Foundation of China under Grant No. 71874184 and the 2019 Chinese Government Scholarship No. 201904910157.

AUTHOR CONTRIBUTIONS

Professor Xiuli Liu designed the model, made the calculation, drafted and edited the manuscript. Ph.D candidate Yuxing Dou collected data, some references and predicted China's urbanization rate.

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