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RESEARCH ARTICLE

Breaking the BMI monotony: an empirical analysis of the effects of China's school feeding program and policy implications for Africa

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KEYWORDS

Physical examination, rural China, school children, school feeding programs

HIGHLIGHTS

- This study incorporates physical fitness test results to evaluate the impact of school feeding programs, providing a multidimensional perspective beyond traditional metrics like height, weight, and BMI.
- The research analyzes data from all primary and secondary school students in the county between 2016 and 2020, offering robust insights into the long-term effects of school feeding programs.
- The study provides practical strategies for improving school feeding programs in Africa by drawing on China's model, emphasizing balanced nutrition, standardized guidelines, and fitness-based evaluations.

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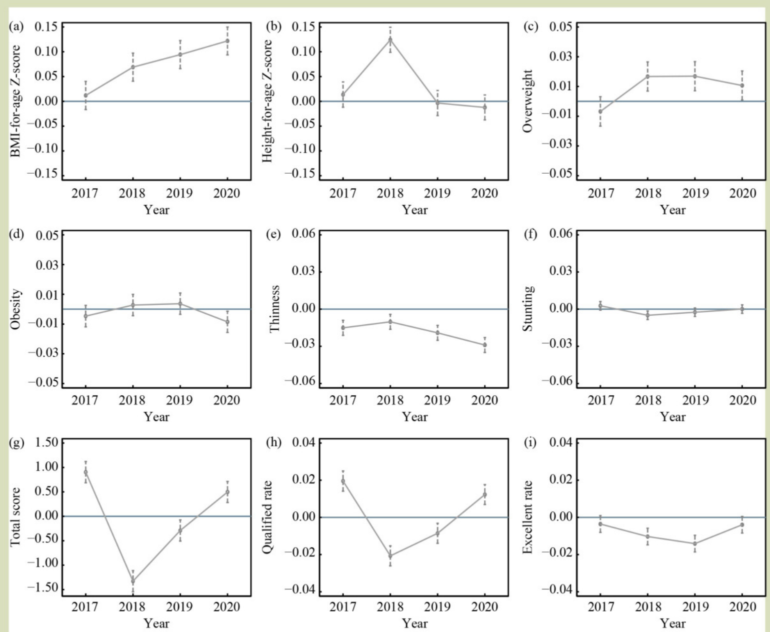
GRAPHICAL ABSTRACT



ABSTRACT

School feeding programs (SFPs) have been extensively implemented as a public policy investment aimed at fostering the development of children across various countries. This study evaluated the impact of the implementation of SFPs on the physical development of school-age children in rural China using a data set comprising over 400 thousand observations. It was found that participation in the Nutrition Improvement Program (NIP) in China promoted the development of height and weight of children in rural schools, and reduced the gap in growth between urban and rural schoolchildren. However, the physical examination performance of children in rural schools was better than that of children in urban schools, and this advantage is gradually expanding with the increase of participation time. This research provides insights for the development and evaluation of SFPs in African countries, including the importance of long-term program participation, targeted interventions to address regional disparities and the use of comprehensive evaluation measures such as physical examination performance. These results provide a framework for enhancing SFPs in Africa, supporting their role in addressing malnutrition, improving education outcomes and driving long-term socioeconomic development.

1 Introduction

A healthy level of human capital is related to personal work enthusiasm and labor efficiency[1,2], and is essential for national economic growth in the long run[3]. A heightened focus on physical health among the general population can be attributed to the improvement of material living standards. Becker[4] indicates that prioritizing human capital investment during adolescence is efficient because the optimal amount of investment declines with age. The importance of ensuring the nutritional and health status of children and adolescents, and providing support for their growth has become a social consensus[5]. School feeding programs (SFPs) are widely adopted as a public policy investment for children, particularly in low- and middle-income countries[6]. The World Food Program[7] reports that there are 388 million children from at least 161 countries at all income levels who participate in SFPs. Short-term benefits from SFPs for school-aged children are reflected in improved academic performance and nutritional intake[8–10]. In the long run, students who participate in SFPs earn higher incomes as adults[11]. The economic efficacy of SFPs is also well established, with the World Food Program of the United Nations reporting in *The State of School Feeding Worldwide 2020*[7] that an effective program can yield up to 9 USD in returns for every 1 USD invested.

SFPs in Africa serve as a critical safety net for impoverished children and their families. These programs not only address the issue of hunger among schoolchildren but also have profound impacts on education, nutrition, social protection and local agriculture. Their implementation contributes to achieving the United Nations Sustainable Development Goal 2: ending hunger, achieving food security and promoting sustainable agriculture. Therefore, these programs represent a significant investment in the current and future well-being of African societies. Numerous studies have demonstrated that SFPs in Africa have increased enrollment rates for girls by 3.2 percentage points and reduced school absenteeism by an average of 1.3 days[12,13]. A study conducted in Ethiopia found that SFPs significantly improved the academic performance of primary school adolescents, showing a statistically significant positive effect on GPA scores with a coefficient of 2.32[14]. Additionally, SFPs have the potential to stimulate local economies by sourcing food from smallholders, thereby strengthening local food systems and alleviating poverty. This approach, commonly referred to as a homegrown school feeding and health program, has been successfully implemented in countries such as Ghana, where it led to a 33% increase in agricultural product sales and household incomes[15]. However, the implementation of homegrown SFPs in Africa still faces many challenges, including low dietary quality (protein and micronutrients were below the desired standard)[16], loss of teaching time[17] and poor food and health environment[18].

In an effort to enhance the nutritional well-being of students in rural areas, the Chinese government launched a SFP called the Nutrition Improvement Program (NIP) for compulsory education students (including six years of primary school and three years of junior high school) in rural schools in 2011. This program provides a daily subsidy of 3 yuan per student to improve their dietary intake. This subsidy was increased to 4 yuan in 2014, and to 5 yuan in 2021[19]. As of September 2020, SFP in China has been implemented in 1762 counties across 29 provinces, covering 84.1% of all rural compulsory education schools and benefiting 42.4% of students, or 40.6 million students in total[20]. Previous studies have shown that SFP participation in China is associated with positive effects of growth and anthropometric indices, the physical and mental health, and cognitive capacity[21–23]. However, other studies have found that the SFP has no significant effect on the adequate access to micronutrient-rich regular diets among students[24]. There are also some challenges in the implementation of SFP, such as a lack of diet with essential nutrients, inadequate sufficient nutrition expertise of the implementers, less patterns of supply for nutritious meals and food security issues[25].

In evaluating the effectiveness of the SFP implementation, previous studies have predominantly focused on changes in student height, weight and BMI. While BMI is widely used as a measure of weight status and provides a static assessment of weight relative to height, it fails to capture the multidimensional aspects of physical health. Physical fitness is a crucial indicator of health that reflects an individual's capability to participate in relevant physical activity or physical exercise[26]. Physical fitness testing is receiving increasing attention as a testing measure of adolescent health[27,28]. In China, physical fitness testing is a comprehensive and systematic evaluation of the physical ability of students includes cardiorespiratory fitness, body composition, muscular strength, endurance and flexibility[29]. A study of adolescents in 13 regions of Shandong Province, China, found that most adolescents meet or surpass the *pass* standard in physical fitness testing, with fewer reaching the *excellent* standard. Adolescents from low socioeconomic status areas had less physical fitness compared to those from high socioeconomic status areas[30]. The results of student fitness testing also provide direction for developing and implementing early health prevention programs to control the obesity epidemic and increase physical activity planning[31,32].

Our study evaluated the effect of SFP on physical fitness of rural students in Ruyang County in Henan Province, focusing on the total score, and pass and excellent rates of student performance in physical fitness tests. The study used physical fitness testing data collected from 2016 to 2020 and covers student height, weight and scores in various athletic ability tests, including short- and long-distance running, jumping rope, sit-ups and standing long jump. We also calculated BMI-for-age Z-scores and height-for-age Z-scores (as BMI-Z and HAZ scores below) based on the World Health Organization (WHO) reference[33], which takes into account the growth differences of children by gender and age, in order to compare the height and weight of the sample students with international standards for children. In addition, the physical fitness test for Chinese students combines different subjects based on gender and age, which can better reflect the overall situation for student physical fitness. Our study is the first to examine the effect of SFP implementation on student physical fitness, and its results provide valuable insights for the evaluation of SFPs in Africa countries.

2 Background

2.1 School feeding programs in Africa

Research shows that many countries have adopted SFPs to support their school-aged children, with goals varying by economic development[34]. In higher-income countries, the focus is on improving child nutrition, while in low- and middle-income countries, SFPs serve as both an educational intervention and a crucial measure to combat hunger and malnutrition, providing a safety net for low-income families. This section examines SFPs in nine African countries, Ethiopia, Ghana, Kenya, Malawi, Mali, Rwanda, South Africa, Uganda and Zimbabwe, highlighting their implementation timelines and impacts. Detailed information on the scope and outcomes of these programs is summarized in Table 1.

SFP implementation began earlier in Ethiopia, Kenya, Malawi and South Africa, all launching in the twentieth century. Ethiopia's School Meals Program started in 1994, offering hot meals to students in food-insecure areas, later expanding to include take-home rations, benefiting 2.54 million students by 2020. In Kenya, school feeding has been active since the 1980s, with 1.75 million students benefiting by 2020. Malawi's program, initiated in 1999, reached 2.94 million students by 2020. South Africa's National School Nutrition Program, launched in 1994, now serves 9.20 million students.

Ghana, Rwanda and Uganda initiated SFPs around 2005. Ghana's SFP began with the aim of reducing poverty and boosting enrollment, benefiting 1.7 million children by 2020. Rwanda's program, implemented on a smaller scale, reached 724 thousand students between 2002 and 2020. Uganda's Food for Education Program, launched in 2005 supported 3.65 million children by 2020. Mali and Zimbabwe began SFPs later, in 2009 and 2016, respectively. Mali's program reached 515 thousand students by 2020 and Zimbabwe's, despite its more recent launch, served 3.22 million children by 2020.

Studies have demonstrated that SFPs improve children's nutritional health and educational outcomes across African countries. Nutritional assessments, detailed in Table 1, measure nutrient intake, dietary diversity and reductions in deficiencies, such as anemia, alongside anthropometric outcomes, such as HAZ and BMI-Z scores. For example, Kenya's homegrown SFP improved dietary diversity, with only 3.5% of the participants in the low dietary diversity group compared to one-third of non-participants[37]. A randomized trial in KwaZulu-Natal, South Africa, found that fortified biscuits significantly increased the intake of vitamin A, iron and iodine among students[42]. Evidence from Uganda and Kenya shows that children enrolled in SFP have a significant reduction in anemia of about 25%[36,43]. Physical growth improvements, such as HAZ and mid-upper arm circumference, were observed in studies on samples from Ghana, Ethiopia and Malawi, with greater benefits seen in students from low-income households[13,35,39]. SFPs also improved educational outcomes,

Table 1 School feeding programs (SFPs) in African countries

Country	Project name	Year	Population covered	Sample	Policy outcome	Reference
Ethiopia	The School Meals Program	1994	By 2020, there were 2,539,000 students benefited	292 children aged 10–14 years in Sidama Zone, Boricha district, Southern Ethiopia	Height-for-age Z-scores (HAZ scores) of students participating in SFP is 0.72 standard deviation (SD) greater than that of students not participating in SFP, and the BMI-for-age Z-scores (BMI-Z scores) of students participating in SFP is 0.57 SD greater than that of students not participating in SFP	[13]
Ghana	Ghana School Feeding Program	2005	By 2020, there were 1,700,000 students benefited	2869 children aged 5–15 years nationwide	HAZ score of children aged 5–8 years increased by 0.12 SD, of which the HAZ score of boys increased by 0.19 SD and by 0.11 SD for girls. For children aged 5–8 living in families below the poverty line it increased by 0.22 SD	[35]
Kenya	School Feeding Program	1980	By 2020, there were 1,754,000 students benefited	67 children at the St. George primary school in Kibera participated in the school feeding program for 1 year	Anemia rate of children participating in the SFP was 19% and that of children in the control group was 42%. Children participating in the school feeding program were less stunted and wasted than children in the control group	[36]
Kenya	Home-Grown School Feeding Program	2009	In 2012, 729,000 schoolchildren benefited from the program in semi-arid sub-counties	288 schoolchildren were sampled in Makindu sub-County in Makueni County	64% of the children participating in the program belong to the medium dietary diversity group, 33.3% of the children belong to the high dietary diversity group, and the children with low dietary diversity account for about 3.5%. Conversely, 53.6% of the children who did not participate in the program were in the medium dietary diversity group, 31.9% of the children belonged to the low dietary diversity group, and 15.5% of the children belonged to the high dietary diversity group	[37,38]
Malawi	Malawian School Feeding Program	1999	By 2020, there were 2,936,000 students benefited	226 schoolchildren aged 6–8 years in 2 rural Malawian public primary schools	Mid-upper arm circumference of children in SFP schools increased by 0.7 cm	[39]
Mali	National School Feeding Program in Mali	2009	By 2020, there were 515,000 students benefited	Used a unique precrisis baseline and five-year follow-up to investigate the effects of emergency school feeding and general food distribution on children’s schooling during conflict in Mali	School feeding increased school enrolment by 10% and increased children’s school attendance by about half a year	[40]
Rwanda	School Feeding Program	2002	By 2020, there were 724,000 students benefited	380 students sampled from 12 schools of Rubavu district	School feeding program had positive and significant influence the examination performance of students	[41]
South Africa	National School Nutrition Program	1994	By 2020, there were 9,200,000 students benefited	Randomized controlled trial conducted by the South African Medical Research Council in rural KwaZulu-Natal	After 12 months of intervention, vitamin A deficiency (serum retinol < 20 $\mu g \cdot dL^{-1}$) dropped from 40% to 12%; anemia from 28% to 15%; and iodine deficiency from 97% to 30%	[42]
Uganda	Food for Education Programs	2005	By 2020, there were 3,651,000 students benefited	672 children aged 6–17 years in northern Uganda	Prevalence rate of anemia among girls aged 10–13 in participating schools was significantly reduced by 25.7%, and incidence rate of moderate and severe anemia was significantly reduced by 19.5%	[43]
Zimbabwe	National School Feeding Program of Zimbabwe (NSFP)	2016	By 2020, there were 3,219,000 students benefited	50 schools in Bulilima district	Policy alternative was tipped to result in improved enrollment (90%), increased attendance (85%), retention (75%) improved nutritional deficiencies (65%) and reduction of hunger (100%)	[44]

with studies from Mali and Zambia indicating increased enrollment and attendance rates[40,44], and evidence from Rwanda shows positive effects on student examination performance[41].

SFPs in Africa have demonstrated positive effects in addressing malnutrition and enhancing school attendance among children. These programs typically relied on standard indicators, such as BMI, HAZ and general nutritional status, to assess their efficacy. While these measures offer valuable insights into children's growth and the alleviation of malnutrition, they are limited in capturing functional health outcomes. Key aspects of physical development, such as cardiovascular endurance, muscular strength, flexibility and overall physical fitness, remain unmeasured. Consequently, these basic indicators do not provide a comprehensive understanding of children's physical capabilities and long-term health potential, underscoring the need for more holistic evaluation methods.

2.2 School feeding program in China

Malnutrition, overweight and obesity among children remain a public health concerns in China[21]. The unbalance economic development between urban and rural has resulted in great differences in nutrition and health of urban children and rural children, with the nutrition and health status of rural children below that of urban children[45]. The NIP was launched in 2011 as a nationwide initiative to enhance the nutritional status of children residing in rural China areas. The primary objective of the program has been to promote educational equity and provide special support to students from underprivileged regions by offering nutritional meal subsidies. The subsidies are available to students in grades 1 to 9 in rural areas. Each student can receive an annual subsidy of 3 yuan (0.45 USD) per day for 200 days, funded by either the central or local finance departments. In recognition of evolving needs and to accommodate inflationary trends, the daily subsidy amount was increased to 4 yuan (0.6 USD) in 2014 and further increased to 5 yuan (0.75 USD) in 2021. As of December 2019, the NIP had been implemented in 1762 counties across 29 provinces in China, benefiting over 40 million impoverished students. The central government allocated a cumulative total of 147 billion yuan (22.1 billion USD) to support the program. Data from the Chinese Center for Disease Control and Prevention indicate that, between 2012 and 2021, the average height increase among boys and girls in NIP-implemented regions was 4.2 and 4.1 cm, respectively, with average weight gains of 3.5 and 3.3 kg. These growth rates surpassed the national average for rural students. Additionally, the stunting rate among students in rural areas of central and western China dropped to 2.5% by 2021, representing a decrease of 5.5 percentage points since 2012.

This study used the data from Ruyang County, which is located in the middle part of Henan Province, China. Ruyang is a National Pilot County for the SFP, which started in the spring semester of 2012, with funding fully provided by the central government. The county government is responsible for creating and executing plans to ensure that subsidy funds are used to provide students with high-quality, equitable food, rather than being given directly to students or parents as cash. County governments also manage the logistics of meal distribution and determine the meal components. The objective is to ensure that nutritional subsidies make a meaningful contribution to underprivileged students. The SFP in Ruyang consisted of two meal offerings: an extra-meal pack that was distributed during class breaks and provided each student with a daily meal of an egg, milk, bread and meat product; the other was a free lunch that was prepared and served by a catering company.

While numerous studies have evaluated the impact of the NIP on nutrition and school performance of students, there remains a gap in research on its effects on physical education quality. Physical fitness tests offer a more comprehensive and dynamic evaluation by assessing cardiovascular endurance, muscular strength, flexibility and coordination[46,47]. These tests also reveal variations in physical function among individuals with similar BMI, enabling the detection of potential risks for chronic diseases that BMI alone cannot identify. Thus, fitness testing serves as a critical tool for monitoring and promoting the overall health and functional development of children. In addition, most existing studies rely on data from one-year periods or discontinuous years. Our study addresses this gap by using continuous data from 2016 to 2020 to evaluate the long-term effects of SFPs on student physical education quality. The findings of this study are expected to inform and guide the implementation of SFPs in Africa.

3 Data and method

3.1 Data collection

Our team collected the physical fitness test data of primary and junior high school students in Ruyang from 2016 to 2020. These data were for 222 primary and secondary schools, including 31 junior high schools, 112 complete primary schools (all students from first to sixth grade) and 79 incomplete primary schools (which are usually located in remote towns with schools for grades 1 to 3 called junior primary schools and grades 5 to 6 called senior primary schools). A total of 345,255 valid observations (5 years) were obtained.

The physical fitness test is an annual examination mandated by the Chinese Ministry of Education and administered to students in compulsory education, including primary and junior high schools, as well as general high school, secondary vocational school and general higher education students. The test assesses physical fitness using the Chinese National Student Physical Fitness Standard[48]. Students are divided into different groups based on grade level or gender, and tested on different indicators. The total score of the physical fitness test consists of standard score and additional score. Standard score is calculated by multiplying the scores of different test subjects by their respective weights and summing these, with a maximum possible score of 100. Additional points are determined based on performance in individual test subjects, with a maximum score of 20.

Our study focused on assessing the physical growth and athletic ability of students in the compulsory education stage, including primary and junior high school students. To evaluate physical growth, we used these indicators: BMI-Z and HAZ scores, overweight, obesity, thinness and stunting. The BMI-Z and HAZ scores were calculated based on the WHO reference[33]. *Overweight* was defined as a dummy variable set to 1 if the BMI-Z score is > 1 standard deviations (SD) or 0 if the BMI-Z score is within the range −2 to 1 SD. *Obesity* was defined as a dummy variable set to 1 if the BMI-Z score is > 2 SD or 0 if the BMI-Z score is within the range −2 to 1 SD. *Thinness* was defined as a dummy variable set to if the BMI-Z score is < −2 SD or 0 if the BMI-Z score is within the range −2 to 1 SD. *Stunting* was defined a dummy variable set to 1 if the HAZ score is < −2 SD or 0 otherwise.

To measure athletic ability, we used the total score and score grade of the physical fitness monitoring test. The total score of the physical fitness test consists of standard score and additional score, ranging from 0 to 120. A total score of ⩾ 90.0 was considered excellent, 80.0–89.9 was good, 60.0–79.9 was qualified and ⩽ 59.9 was failing. The score grade was represented by two additional dummy variables, *qualified* and *excellent*. If the score is ⩾ 60.0, *qualified* is set to 1 or 0 otherwise, and if the score is ⩾ 90.0, *excellent* is set to 1 or 0 otherwise.

In the context of improving nutrition for children in rural areas of China, the nutrition improvement program was implemented in rural schools, rather than for children with rural household registration. Our study uses "attendance at a rural school" as a proxy for participation in the nutrition improvement program. We also controlled for individual characteristics such as gender and grade level, in consideration of the disparity in student physical fitness.

The results presented in Table 2 indicate that the mean HAZ score was about 0.293, the mean BMI-Z score was about 0.091 and the proportion of boys was about 51.6%. Additionally, about 64.7% of the students were from rural schools and participate in the SFP.

3.2 Statistical analysis

To analyze the impact of the SFP on the physical health and athletic ability of rural students, we used urban school students

Table 2 Statistics of dependent variables, independent variables and control variables

Variable	Definition	Observation	Mean	Standard deviation
BMI-Z	BMI-for-age Z-score (BMI-Z score)	345,255	0.091	1.243
HAZ	Height-for-age Z-score (HAZ score)	345,255	0.293	1.118
Overweight	Dummy variable; set to 1 if a student is overweight or 0 if normal	330,138	0.232	/
Obesity	Dummy variable; set to 1 if a student is obesity or 0 if normal	277,828	0.088	/
Thinness	Dummy variable; set to 1 if a student is thin or 0 if normal	268,616	0.056	/
Stunting	Dummy variable; set to 1 if a student is stunting or 0 otherwise	345,255	0.023	/
Total score	Total score of student physical fitness test results	345,255	75.418	9.748
Qualified rate	Dummy variable; set to 1 if the total score of a student > 60.0 or 0 otherwise	345,255	0.940	/
Excellent rate	Dummy variable; set to 1 if the total score of a student > 90.0 or 0 otherwise	345,255	0.040	/
Boy	Dummy; set to 1 if the student is male or 0 if female	345,255	0.516	/
Grade	Grade level of a student	345,255	4.846	2.559
Rural	Dummy variable; set to 1 if a student goes to rural school or 0 otherwise	345,255	0.647	/

who did not participate in the SFP as a control group. We used the ordinary least squares model without the intercept to analyze the relationship between whether to participate in the SFP and the physical health of rural students:

$$Y_{it} = \beta_1 Rural + \beta_2 Year + \beta_3 Rural \times Year + \beta_4 D + \varepsilon_{it}$$

where, Y_{it} is the outcome variable including physical development indicators and athletic ability indicators for student, such as HAZ and BMI-Z scores, overweight, obesity, thinness and stunning. We also used total score of physical fitness test, qualified rate and excellent rate to represents the physical fitness of students. *Rural* indicates whether a student went to a rural school, that is, whether to participate in the SFP (dummy variable is set to 1 if a student goes to rural school or 0 otherwise). *Year* is a set of dummy variables for the years 2016 to 2020, and *D* is a vector of control variables that includes gender and grade of a student. The term ε_{it} is the error.

4 Results

4.1 Sample characteristics

Table 3 presents the basic characteristics and athletic ability development of the samples. The physical development of students improved from 2016 to 2020, but the physical development of rural school students was still inferior to that of urban school students. While the student physical fitness test performance declined slightly, rural school students outperformed urban school students. In general, there were significant increases in the mean levels of HAZ and BMI-Z scores among students, with a greater change observed in the BMI-Z score among rural school students compared to urban school students. The overweight and obesity rates of rural and urban school students increased slightly, with rural school students having a greater increase in overweight rates and urban school students having a greater increase in obesity rates. In addition, the level of thinness among rural school students declined slightly but there was a slight increase among urban school students. The level of stunting among rural and urban school students decreased by the same magnitude between 2016 and 2020. For physical activity development, the mean total score and *excellent* rate of physical fitness tests showed a slight decrease from 2016 to 2020, while the *pass* rate of physical fitness tests showed a slight increase, with the increase in rural school students slightly above that in urban school students.

Table 3 Descriptive statistics of student physical development of physical fitness test data

Variable	Year	Rural school	Diff.	Urban school	Diff.
BMI-Z	2016	–0.02 (1.21)	0.20***	0.15 (1.22)	0.09***
	2020	0.17 (1.24)		0.24 (1.34)	
HAZ	2016	0.10 (1.11)	0.26***	0.35 (1.16)	0.28***
	2020	0.35 (1.07)		0.63 (1.08)	
Overweight	2016	0.20 (0.40)	0.05***	0.25 (0.43)	0.04***
	2020	0.25 (0.43)		0.29 (0.46)	
Obesity	2016	0.06 (0.24)	0.03***	0.09 (0.29)	0.05***
	2020	0.09 (0.30)		0.14 (0.46)	
Thinness	2016	0.06 (0.24)	–0.01***	0.05 (0.21)	0.02***
	2020	0.05 (0.22)		0.06 (0.24)	
Stunting	2016	0.03 (0.18)	–0.02***	0.03 (0.16)	–0.02***
	2020	0.02 (0.12)		0.01 (0.10)	
Total score	2016	78.0 (9.28)	–1.01***	74.0 (10.38)	–1.25***
	2020	76.6 (8.44)		72.8 (9.47)	
Qualified rate	2016	0.96 (0.20)	0.02***	0.91 (0.29)	0.01**
	2020	0.98 (0.15)		0.92 (0.27)	
Excellent rate	2016	0.07 (0.25)	–0.02***	0.04 (0.19)	–0.02***
	2020	0.04 (0.20)		0.02 (0.14)	

Note: Standard deviation in parentheses. *** $p < 0.01$, ** $p < 0.05$.

4.2 School feeding program effects on physical development and fitness

Table 4 presents the effect of student participation in SFP on indicators of student physical development and fitness. Figure 1 gives a visual representation of the coefficients. The growth in BMI-Z scores of students participating in SFP exceeded that of non-participating students by 0.069 SD ($p < 0.01$) in 2018. This difference progressively increased over the years, reaching 0.122 SD ($p < 0.01$) by 2020. For overweight and obesity, the difference in overweight rates between students participating in the SFP and those not participating remained almost unchanged from 2017 to 2020. However, by 2020, the obesity rate among SFP participants was significantly below that of non-participants by 0.9 percentage points ($p < 0.05$). The prevalence of thinness among SFP participants was below that of non-participants by 1.5% to 2.9%. Regarding the total scores, students participating in SFP scored 1.33 points below non-participating students ($p < 0.01$) in 2018. However, by 2020, the total scores of participating students exceeded those of non-participating students by 0.50 points ($p < 0.01$). In 2020, SFP participants had increased pass rates in physical fitness tests compared to non-participants, although their rates of achieving excellence were decreased. Additionally, the results indicated that boys had greater BMI-Z and HAZ scores than girls but also had increased rates of overweight, obesity

Table 4 Effect of nutrition improvement program on physical development and fitness indicators

Variable	Physical development						Physical fitness		
	BMI-Z	HAZ	Overweight	Obesity	Thinness	Stunting	Total score	Qualified rate	Excellent rate
Rural&2017	0.012	0.014	−0.007	−0.005	-0.015^{***}	0.003	0.904^{***}	0.020^{***}	−0.004
	(0.015)	(0.013)	(0.005)	(0.004)	(0.003)	(0.002)	(0.111)	(0.003)	(0.002)
Rural&2018	0.069^{***}	0.124^{***}	0.017^{***}	0.003	-0.010^{***}	-0.005^{***}	-1.328^{***}	-0.021^{***}	-0.010^{***}
	(0.014)	(0.013)	(0.005)	(0.004)	(0.003)	(0.002)	(0.110)	(0.003)	(0.002)
Rural&2019	0.094^{***}	−0.003	0.017^{***}	0.004	-0.019^{***}	−0.002	-0.290^{***}	-0.009^{***}	-0.014^{***}
	(0.014)	(0.013)	(0.005)	(0.004)	(0.003)	(0.002)	(0.110)	(0.003)	(0.002)
Rural&2020	0.122^{***}	−0.012	0.011^{**}	-0.009^{**}	-0.029^{***}	0.000	0.498^{***}	0.012^{***}	-0.004^{*}
	(0.014)	(0.013)	(0.005)	(0.004)	(0.003)	(0.002)	(0.110)	(0.003)	(0.002)
Rural	-0.205^{***}	-0.285^{***}	-0.058^{***}	-0.032^{***}	0.018^{***}	0.006^{***}	2.994^{***}	0.041^{***}	0.024^{***}
	(0.011)	(0.010)	(0.004)	(0.003)	(0.002)	(0.001)	(0.082)	(0.002)	(0.002)
Year = 2016	0.254^{***}	0.504^{***}	0.249^{***}	0.093^{***}	0.031^{***}	0.022^{***}	77.989^{***}	0.963^{***}	0.056^{***}
	(0.010)	(0.009)	(0.004)	(0.003)	(0.002)	(0.001)	(0.078)	(0.002)	(0.002)
Year = 2017	0.276^{***}	0.520^{***}	0.261^{***}	0.103^{***}	0.039^{***}	0.016^{***}	77.228^{***}	0.954^{***}	0.051^{***}
	(0.009)	(0.008)	(0.003)	(0.002)	(0.002)	(0.001)	(0.072)	(0.002)	(0.001)
Year = 2018	0.234^{***}	0.501^{***}	0.250^{***}	0.101^{***}	0.039^{***}	0.022^{***}	78.325^{***}	0.979^{***}	0.046^{***}
	(0.009)	(0.008)	(0.003)	(0.002)	(0.002)	(0.001)	(0.070)	(0.002)	(0.001)
Year = 2019	0.285^{***}	0.709^{***}	0.270^{***}	0.114^{***}	0.042^{***}	0.011^{***}	76.053^{***}	0.953^{***}	0.039^{***}
	(0.009)	(0.008)	(0.003)	(0.002)	(0.002)	(0.001)	(0.069)	(0.002)	(0.001)
Year = 2020	0.349^{***}	0.792^{***}	0.299^{***}	0.140^{***}	0.047^{***}	0.005^{***}	76.770^{***}	0.973^{***}	0.039^{***}
	(0.009)	(0.008)	(0.003)	(0.002)	(0.002)	(0.001)	(0.068)	(0.002)	(0.001)
Boy	0.227^{***}	0.119^{***}	0.093^{***}	0.067^{***}	0.014^{***}	0.000	-1.016^{***}	-0.021^{***}	0.013^{***}
	(0.004)	(0.004)	(0.001)	(0.001)	(0.001)	(0.001)	(0.032)	(0.001)	(0.001)
Grade	-0.044^{***}	-0.043^{***}	-0.010^{***}	-0.007^{***}	0.002^{***}	0.001^{***}	-0.667^{***}	-0.008^{***}	-0.005^{***}
	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.006)	(0.000)	(0.000)
Observations	345,255	345,255	330,138	277,828	268,616	345,255	345,255	345,255	345,255
R^2	0.026	0.095	0.248	0.109	0.058	0.025	0.985	0.942	0.050

Note: Standard errors in parentheses. *** $p < 0.01$ and ** $p < 0.05$. For the categories of overweight, obesity, and thinness, the control group in the sample is defined as the normal group (with BMI-Z scores falling within the range of −2 to 1 SD).

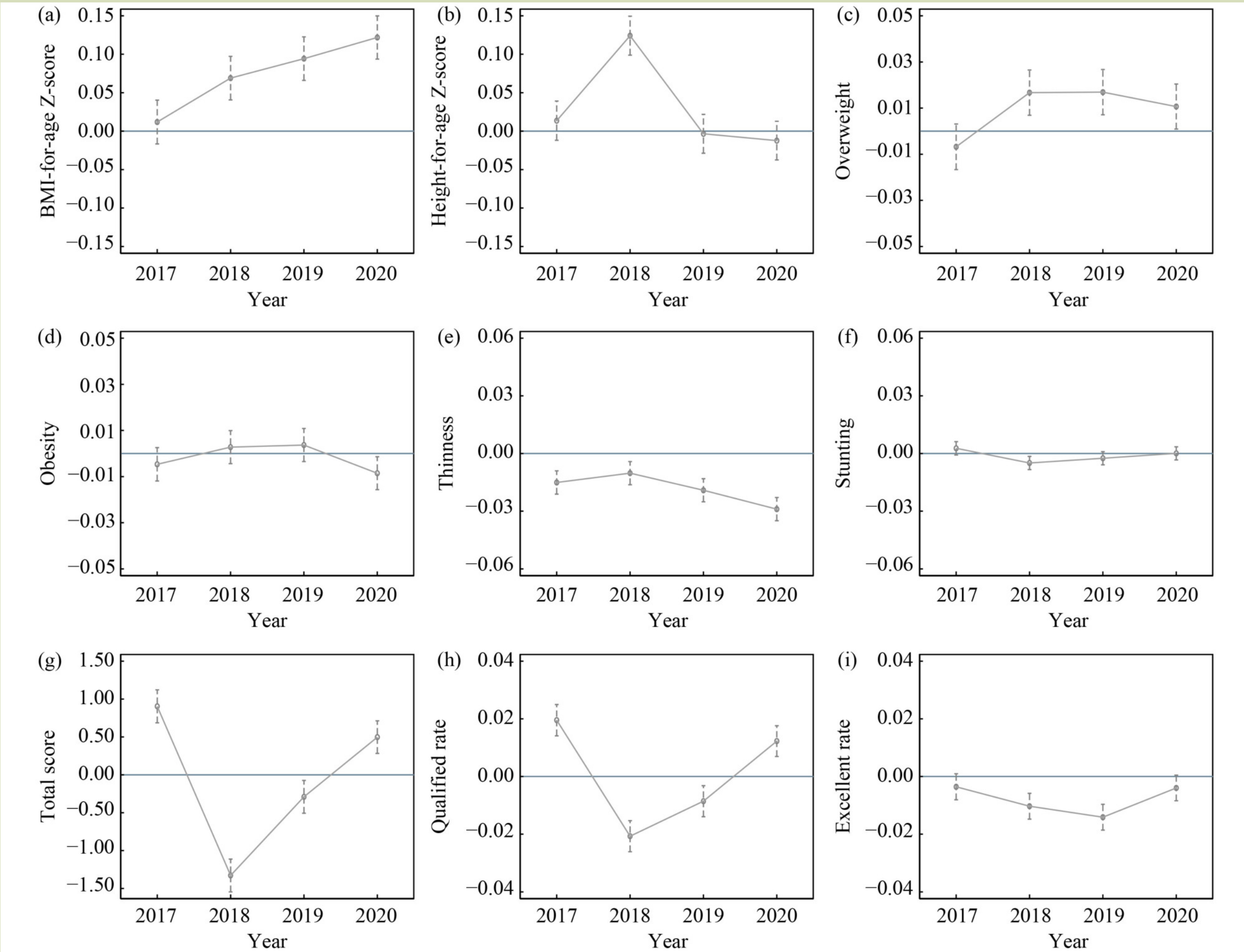


Fig. 1 Coefficient chart of the impact of the nutrition improvement plan on physical development and health indicators. (a) BMI-for-age Z-score (BMI-Z score); (b) height-for-age Z-score (HAZ score); (c) overweight; (d) obesity; (e) thinness; (f) stunting; (g) total score; (h) qualified rate; (i) excellent rate.

and thinness. Also, lower grade students had increased BMI-Z and HAZ scores compared to higher grade students, with decreased rates of thinness and stunting but increased prevalence of overweight and obesity.

Table 5 presents the effect of the SFP on physical development indicators from primary school and junior high school students. The growth in BMI-Z scores of primary school students participating in SFP increased annually, surpassing those of non-participating students by 0.065 SD ($p < 0.01$) in 2017 and further rising to 0.080 SD ($p < 0.01$) by 2020. Concurrently, the growth in BMI-Z scores of junior high school students participating in SFP increased by 0.221–0.234 SD compared to non-participating students. Primary school students participating in the SFP had decreased obesity rates than non-participating students, but junior high school students participating in the SFP had slightly greater rates of overweight and obesity than non-participating students. In 2017, the prevalence of thinness among primary school students participating in the SFP was 0.9% below that of non-participants ($p < 0.01$), and this difference increased to 2.7 percentage points by 2020 ($p < 0.01$). Similarly, among junior high school students, participation in the SFP was associated with a significant reduction in the prevalence of thinness, consistently remaining 2.6%–3.9% below non-participating students.

Table 6 presents the effects of the SFP on the physical fitness outcomes of primary and junior high school students. Among primary school students participating in the SFP, their total scores improved from being 1.06 points below those of non-participants ($p < 0.01$) to 1.232 points above non-participants

Table 5 Results of the effect of nutrition improvement program on physical development indicators from primary school and junior high school students

Variable	Primary school student						Junior high school student					
	BMI-Z	HAZ	overweight	obesity	thinness	stunting	BMI-Z	HAZ	overweight	obesity	thinness	stunting
Rural&2017	−0.065***	0.011	−0.023***	−0.011**	−0.009**	0.003	0.221***	−0.045**	0.034***	0.007	−0.036***	0.004
	(0.018)	(0.016)	(0.006)	(0.005)	(0.004)	(0.002)	(0.024)	(0.021)	(0.008)	(0.005)	(0.005)	(0.003)
Rural&2018	0.050***	0.224***	0.016**	0.002	−0.005	−0.014***	0.162***	−0.146***	0.031***	0.006	−0.026***	0.016***
	(0.018)	(0.016)	(0.006)	(0.005)	(0.004)	(0.002)	(0.024)	(0.021)	(0.008)	(0.005)	(0.005)	(0.003)
Rural&2019	0.042**	0.064***	0.003	−0.007	−0.019***	−0.008***	0.241***	−0.225***	0.051***	0.019***	−0.028***	0.010***
	(0.018)	(0.016)	(0.006)	(0.005)	(0.004)	(0.002)	(0.024)	(0.021)	(0.008)	(0.005)	(0.005)	(0.003)
Rural&2020	0.080***	−0.008	−0.001	−0.018***	−0.027***	−0.000	0.234***	−0.142***	0.037***	0.004	−0.039***	0.006**
	(0.018)	(0.016)	(0.006)	(0.005)	(0.004)	(0.002)	(0.024)	(0.021)	(0.008)	(0.005)	(0.006)	(0.003)
Rural	−0.112***	−0.340***	−0.043***	−0.028***	0.004	0.005***	−0.455***	−0.086***	−0.105***	−0.043***	0.048***	0.004*
	(0.013)	(0.012)	(0.005)	(0.004)	(0.003)	(0.002)	(0.019)	(0.016)	(0.006)	(0.004)	(0.004)	(0.002)
Year fixed	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Control variable	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observation	240,410	240,410	230,444	191,507	181,957	240,410	104,845	104,845	99,694	86,321	86,659	104,845
R^2	0.032	0.105	0.268	0.122	0.056	0.028	0.035	0.111	0.205	0.077	0.064	0.029

Note: Standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$. For the categories of overweight, obesity, and thinness, the control group in the sample is defined as the normal group (with BMI-Z scores falling within the range of −2 to 1 SD).

Table 6 Results of the effect of nutrition improvement program on physical fitness from primary school and junior high school students

Variable	Primary school student			Junior high school student		
	Total score	Qualified rate	Excellent rate	Total score	Qualified rate	Excellent rate
Rural&2017	1.163***	0.027***	−0.009***	0.412*	0.009	0.006*
	(0.133)	(0.003)	(0.003)	(0.212)	(0.006)	(0.003)
Rural&2018	−1.055***	−0.008***	−0.017***	−1.797***	−0.045***	0.007*
	(0.132)	(0.003)	(0.003)	(0.212)	(0.006)	(0.003)
Rural&2019	−0.362***	−0.003	−0.025***	0.145	−0.015**	0.011***
	(0.131)	(0.003)	(0.003)	(0.211)	(0.006)	(0.003)
Rural&2020	1.232***	0.038***	−0.013***	−0.425**	−0.023***	0.021***
	(0.129)	(0.003)	(0.003)	(0.212)	(0.006)	(0.003)
Rural	2.829***	0.024***	0.033***	3.126***	0.065***	0.006**
	(0.097)	(0.002)	(0.002)	(0.163)	(0.005)	(0.003)
Year fixed	Yes	Yes	Yes	Yes	Yes	Yes
Control variable	Yes	Yes	Yes	Yes	Yes	Yes
Observation	240,410	240,410	240,410	104,845	104,845	104,845
R^2	0.986	0.957	0.055	0.981	0.904	0.042

Note: Standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$

by 2020 ($p < 0.01$). In contrast, while SFP-participating junior high school students had increased total scores than non-participants in 2017, their scores fell below those of non-participants by 2020.

Additionally, the pass rates for physical fitness tests among SFP-participating primary school students consistently exceeded those of non-participating students whereas the pass rates for SFP-participating junior high school students remained consistently below their non-participating peers. Also, the excellent rates among SFP-participating primary school students were generally below those of non-participants, and this trend was also observed among junior high school students, whose excellent rates were consistently below those of non-participants.

There were significant differences between boys and girls for physical development and fitness. The results presented in Table 7 show that the increase in BMI-Z scores among boys participating in SFP was greater than those who did not participate, ranging from 0.061 to 0.125 SD ($p < 0.01$). Meanwhile, girls participating in SFP had a greater increase in BMI-Z scores, ranging from 0.077 to 0.120 SD. The prevalence of overweight and obesity among SFP-participating boys was below that of non-participating boys. In contrast, SFP-participating girls had increase rates of overweight and obesity compared to their non-participating counterparts. The thinness rate among SFP-participating boys was 1.9%–3.8% below that of non-participating boys ($p < 0.01$). For girls, the thinness rate among SFP participants was 1.1%–2.0% below that of non-participating girls.

Table 8 presents the effects of the SFP on the physical fitness outcomes of boys and girls. In 2018, the total scores of SFP-participating boys increased from being 1.09 points below those of non-participating boys ($p < 0.01$) to 0.90 points higher ($p < 0.01$). However, the total scores of SFP-participating girls consistently remained below those of non-participating girls. The pass rates for SFP-participating boys improved, increasing from 2.7% below non-participants to 1.7% above. Similarly, the pass rates for SFP-participating girls increased from 1.3% below non-participants to 0.8% above. However, the excellent rates of SFP-participating girls consistently remained below those of non-participating girls.

5 Discussion

5.1 The impact of SFP on students' physical development and fitness

The aim of the study was to investigate the effect of SFP on the physical development and fitness of the students. We observed positive responses in terms of student BMI-Z scores and thinness indicators. Specifically, we find that the increase in BMI-Z scores for rural school students compared to urban school students increase from annually with longer participation in SFP. Concurrently, we observed that the rate of thinness in rural schools decreased more than for students in

Table 7 Results of the effect of nutrition improvement program on physical development indicators for boys and girls

Variable	Boy						Girl					
	BMI-Z	HAZ	Overweight	Obesity	Thinness	Stunting	BMI-Z	HAZ	Overweight	Obesity	Thinness	Stunting
Rural&2017	0.000	0.023	-0.015^{**}	-0.012^{**}	-0.019^{***}	0.003	0.025	0.004	0.002	0.003	-0.011^{***}	0.003
	(0.021)	(0.018)	(0.007)	(0.006)	(0.005)	(0.002)	(0.020)	(0.018)	(0.007)	(0.004)	(0.004)	(0.003)
Rural&2018	0.061^{***}	0.085^{***}	0.008	−0.007	-0.014^{***}	0.001	0.077^{***}	0.167^{***}	0.026^{***}	0.013^{***}	−0.006	-0.011^{***}
	(0.021)	(0.018)	(0.007)	(0.006)	(0.005)	(0.002)	(0.019)	(0.018)	(0.007)	(0.004)	(0.004)	(0.003)
Rural&2019	0.091^{***}	-0.054^{***}	0.009	−0.005	-0.027^{***}	0.000	0.097^{***}	0.053^{***}	0.026^{***}	0.013^{***}	-0.011^{***}	-0.005^{**}
	(0.021)	(0.018)	(0.007)	(0.006)	(0.005)	(0.002)	(0.019)	(0.018)	(0.007)	(0.004)	(0.004)	(0.003)
Rural&2020	0.125^{***}	-0.046^{**}	0.007	-0.018^{***}	-0.038^{***}	0.001	0.120^{***}	0.026	0.015^{**}	0.001	-0.020^{***}	−0.001
	(0.021)	(0.018)	(0.007)	(0.006)	(0.005)	(0.002)	(0.019)	(0.018)	(0.007)	(0.004)	(0.004)	(0.003)
Rural	-0.237^{***}	-0.310^{***}	-0.065^{***}	-0.039^{***}	0.023^{***}	0.006^{***}	-0.169^{***}	-0.259^{***}	-0.050^{***}	-0.024^{***}	0.012^{***}	0.007^{***}
	(0.016)	(0.014)	(0.005)	(0.004)	(0.003)	(0.002)	(0.015)	(0.014)	(0.005)	(0.003)	(0.003)	(0.002)
Year fixed	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Control variable	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observation	178,271	178,271	169,979	139,719	131,109	178,271	166,984	166,984	160,159	138,109	137,507	166,984
R^2	0.037	0.120	0.285	0.132	0.064	0.026	0.012	0.066	0.190	0.061	0.050	0.025

Note: Standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$. For the categories of overweight, obesity, and thinness, the control group in the sample is defined as the normal group (with BMI-Z scores falling within the range of −2 to 1 SD).

Table 8 Effect of nutrition improvement program on physical fitness indicators for boys and girls

Variable	Boy			Girl		
	Total score	Qualified rate	Excellent rate	Total score	Qualified rate	Excellent rate
Rural&2017	1.181***	0.023***	0.001	0.592***	0.016***	−0.008***
	(0.162)	(0.004)	(0.003)	(0.151)	(0.004)	(0.003)
Rural&2018	−1.094***	−0.027***	−0.003	−1.589***	−0.013***	−0.019***
	(0.161)	(0.004)	(0.003)	(0.150)	(0.004)	(0.003)
Rural&2019	0.046	−0.010**	−0.008**	−0.656***	−0.006*	−0.021***
	(0.161)	(0.004)	(0.003)	(0.150)	(0.004)	(0.003)
Rural&2020	0.900***	0.017***	0.009***	0.058	0.008**	−0.018***
	(0.160)	(0.004)	(0.003)	(0.149)	(0.004)	(0.003)
Rural	3.016***	0.051***	0.019***	2.973***	0.030***	0.029***
	(0.120)	(0.003)	(0.003)	(0.113)	(0.003)	(0.002)
Year fixed	Yes	Yes	Yes	Yes	Yes	Yes
Control variable	Yes	Yes	Yes	Yes	Yes	Yes
Observation	178,271	178,271	178,271	166,984	166,984	166,984
R^2	0.983	0.931	0.052	0.987	0.953	0.047

Note: Standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$.

urban schools each year and the rate of decline gradually increased with time. It means that the implementation of nutritious meals has promoted the physical development of rural students. Similar effects have been observed in SFPs in some African countries[13,35].

Physical activity during childhood and adolescence can have a positive impact on health by maintaining energy balance, promoting bone growth and improving cardiorespiratory endurance[49]. Studies have shown that in addition to innate genetic factors, acquired environment factors, such as nutrient intake during children's growth, also have a great impact on cardiorespiratory endurance and physical performance[50,51]. Compared with urban school students, rural school students participating in SFP had better achievements in terms of total score, qualified rate and excellent rate in physical fitness tests, which is consistent to the results of an earlier study that compared with children living in urban and rural areas with those in rural areas more likely to achieve the fitness standards[29]. It is also worth noting that boys have a qualified rate below that of girls, but an increased excellent rate. Students in lower grades had better athletic ability than students in higher grades, which may be due to less time spent on physical activity as course load increases as grades progress.

Physical fitness may vary according to school grade and age. Indeed, significant changes may occur in areas of physical development as children age. Therefore, our study divided all samples by school stage for a heterogeneity analysis. Specifically, in the sample of junior high school students, the difference in BMI-Z scores, thinness, total score and pass rate between rural school students and urban school students is bigger than that of primary school students, which may be because junior high school students benefit from SFP for a longer period of time, and their growth and development change more obvious. In addition, we found that the HAZ scores of rural primary school students increased more than those of urban primary school students, but the sample of junior high school students showed the opposite trend, which may be related to the faster growth of junior high school students in adolescence[52].

Our study also divided all samples by gender. As mentioned previously, the thinness rates between boys in rural schools and urban schools were above those of girls. In particular, the rate of stunting decline among rural school students was also greater than that of urban school students in the girl samples. This finding confirms the effectiveness of SFP in improving the health and nutritional status of rural school students, especially for girls. We also find that the sample of boys had a larger score gap between rural school students and urban school students. This could be attributed to the fact that boys tend to engage in outdoor sports and physical activity of greater intensity than girls[53,54].

SFPs in China have provided practical strategies to address the major challenges faced by those in Africa. These programs are centered on providing balanced and diverse meals tailored to children's nutritional needs for growth and development, implementing standardized nutritional guidelines, alongside offering nutrition education to students. These efforts aim to holistically improve student physical health and our research findings confirm the significant benefits the SFPs in achieving this objective. Also, our findings offer valuable insights for the comprehensive evaluation of SFP effectiveness. Reports indicate that 87% of African countries have established national school feeding monitoring systems[55]; however, inconsistencies in data reporting remain a significant challenge. Implementing systematic monitoring of students' nutritional and health status, along with standardized data indicators, is crucial for assessing program implementation across regions. This approach enables a comprehensive evaluation of the impact of school feeding programs on beneficiaries' dietary intake, nutritional status, growth, and health. Specifically, physical fitness tests not only underscore the overall health benefits of improved nutrition but also highlight specific areas for targeted interventions, such as enhancing strength or agility within particular age groups. Incorporating these multidimensional measures can significantly improve the effectiveness of SFPs by addressing demographic factors, such as gender and age. By using physical fitness as a measurement metric, programs can develop targeted interventions to enhance specific aspects of physical well-being, providing practical value for both public and school health initiatives.

5.2 Limitations

The data used in this study were obtained from a county in central China. Considering that SFPs have been piloted throughout various regions in the country, the conclusions drawn from this study might not represent the average situation in other provinces. Also, the control group in this study consisted of students from urban schools, who generally come from families with better economic conditions compared to students from rural schools. Therefore, there may be an underestimation of the positive effects of the SFP. Lastly, this study did not control for fixed effects at the school level, which regards careful examination when identifying causal relationships. Nevertheless, the findings of this study can serve as a reference for mean comparisons within the cohort.

6 Conclusions and implications

6.1 Conclusions

SFPs have been implemented in many countries, especially in some developing countries including China and many African countries. Many studies have found that the implementation of SFP can improve the nutrition and health status of schoolchildren, but there is still a lack of evaluation on student physical education examination performance. We analyzed the effects of SFP on student health and physical fitness using over 300 thousand student physical fitness monitoring data from 2016 to 2020 in rural China. We found that participation in SFP had a positive effect on student health and the performance on physical education tests. With time, this influence will increase. Specifically, the BMI-Z scores of students in rural schools were still below those in urban schools, but the gap is gradually narrowing. The rate of thinness among students in rural schools was also decreasing. Second, students from rural schools performed better on fitness monitoring than students from urban schools. From the perspective of this specific gap each year, the total score and qualified rate of the physical fitness test of rural school students gradually increased from the level below that of urban school students to one above that of urban school students. According to the results of subsamples, junior high school students have an increased excellent rate of physical fitness monitoring results than primary school students, but decreased excellent rate. In addition, boys show a larger gap in physical development indicators between urban and rural school students than girls.

6.2 Implications for research and practice

Children's nutritional health requires close attention from various aspects including families and society. Children from lower socioeconomic backgrounds commonly have an increased prevalence of nutritional deficiencies or overweight and obesity issues. The findings of this study have practical implications for school communities and educators. At the school community level, providing more opportunities for nutritious meals during the school day can have a significant impact on students from lower socioeconomic backgrounds, especially rural left-behind children. In addition, our study adds an examination of different types of physical examination subjects for students and analyzes the gaps in performance between students involved in SFP and those not involved in SFP. Our study provides a new direction for the evaluation of the effectiveness of SFP in developing countries.

Also, the implementation of SFPs in African countries and regions provides a valuable insight for consideration. The homegrown SFP model offers an exemplary approach, prioritizing the procurement of food from local agricultural producers. This strategy fosters a symbiotic relationship between educational programs and rural economic development, while simultaneously strengthening the resilience of the school feeding supply chain, ensuring a stable and sustainable source of nutrition for students.

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Compliance with ethics guidelines

Ying Zhang, Yu Wang, and Qiran Zhao declare that they have no conflicts of interest or financial conflicts to disclose. This article does not contain any studies with human or animal subjects performed by any of the authors.

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