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The impact of COVID-19 on livelihood assets: a case study of high-value crop farmers in North-West Bangladesh

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The COVID-19 pandemic has had a catastrophic impact on public health, extending to the food system and people's livelihoods worldwide, including Bangladesh. This study aimed to ascertain the COVID-19 pandemic impacts on livelihood assets in the North-Western areas (Rajshahi and Rangpur) of Bangladesh. Primary data were collected from 320 farmers engaged in high-value agriculture using a multistage sampling method. The data were analysed using first-order structural equation modelling. The findings reveal a significant impact ($p < 0.01$) of the pandemic on all livelihood assets in Bangladesh. Notably, human assets exhibited the highest impact, with a coefficient of 0.740, followed sequentially by financial (0.709), social (0.684), natural (0.600), physical (0.542), and psychological (0.537) assets. Government-imposed lockdowns and mobility restrictions were identified as the major causes of the pandemic's negative effects on livelihoods, which included lost income, rising food prices, decreased purchasing power, inadequate access to food and medical supplies, increased social insecurity, and a rise in depression, worry, and anxiety among farmers. The effects of COVID-19 and associated policy measures on the livelihoods of high-value crop farmers have reversed substantial economic and nutritional advances gained over the previous decade. This study suggests attention to the sustainable livelihoods of farmers through direct cash transfer and input incentive programs to minimize their vulnerability to a pandemic like COVID-19 or any other crisis in the future.

Keywords Epidemic, Livelihood assets vulnerability, Farming impact, Structural equation, High-value crops, Bangladesh

The SARS-CoV-2 virus, which causes COVID-19, emerged as a threat to public health around the world, and on March 11, 2020, it was declared a worldwide pandemic by the World Health Organization[1]. In Bangladesh, the disease was first detected on March 7, 2020[2]. Bangladesh experienced its 1st phase of lockdown in March–May 2020, drastically disrupted food value chains by restricting the movement of people and commodities. This distribution led to growing rates of food loss and waste, supply chain disruption, and declining product demand[2]. Globally, food insecurity rose due to the disruption of supply chains, resulting in prices and production costs[3].

The COVID-19 pandemic presents an opportunity to study a severe shock to food systems and underscores the importance of access to livelihood assets in buffering against such shocks. Livelihood assets refer to the resources and capabilities that individuals and communities possess, influencing their ability to cope with stresses and shocks and to recover and maintain their livelihoods sustainably[4,5]. People in developing nations rely on a variety of resources, including capital and assets, to support their daily lives. Five subsistence assets—natural, physical, financial, human, and social—are used to classify livelihood assets[6]. Psychological factors were added

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based on the COVID-19 pandemic situation. These assets play an important role in the survival of sustainable rural and urban livelihoods[7]. Not all shocks are anticipated to have the same impact on assets and outcomes related to livelihoods, but shocks such as the pandemic can undermine some or all assets and have a detrimental impact on livelihoods[8].

The COVID-19 has profoundly affected various aspects of life globally. Previous outbreaks, such as Middle East respiratory syndrome (MERS), severe acute respiratory syndrome (SARS), and Ebola, have been extensively studied and have shown to significantly disrupt agricultural labor and output[9–11]. The substantial impacts of COVID-19 on agriculture underscore the importance of a sustainable livelihood strategy that considers different capital assets—natural, economic, financial, human, and social[12–17]. The multidimensional effects of the epidemic on employment, food availability, and market dynamics have resulted in significant food insecurity for daily wage workers[18–20]. Due to COVID-19, there have been substantial disruptions in agricultural productivity and food value chains, as identified in prior research. Due to labor shortages, transportation restrictions, and difficulties in obtaining agricultural inputs have led to increased production costs[21,22]. Farmers also encountered challenges in harvesting crops and transporting products to the market, resulted in higher food transportation costs[23]. Labor shortages, further impeded productivity and market access was restricted for sellers and purchasers due to travel restrictions[24–27]. Furthermore, financial challenges faced by farmers were exacerbated by a decrease in consumer demand for perishables, price increases, and reduced earnings among informal laborers[28,29].

This study focuses on farmers engaged in the production of high-value agriculture, such as vegetables. In general, agricultural products that are eaten either fresh or processed and have a substantially higher value (per weight or unit) in the market are considered high-value agriculture[30]. In developing countries like Bangladesh, high-value agricultural practices are important to achieve the sustainable development goals (SDG), particularly SDG 2.3, which describes 2030 as a doubling of the agricultural productivity and incomes of small-scale food producers[31]. Previous studies have examined the impact of COVID-19 on rural livelihood, food safety, dietary diversity, and food security[18,32–37]. However, no systematic study has been found concerning how the pandemic impacted the livelihood assets of farmers engaged in high-value agriculture.

The study was conducted in four districts of the North-Western (NW) region of Bangladesh, a region with considerable agricultural significance and vulnerability to natural and socioeconomic challenges. The decision to focus on this region was based on its diverse livelihoods, potential for policy impact, and the need to address existing research gaps. Farmers in this region continuously fight against natural disasters, illiteracy, and other development problems[38]. This study offers several novel aspects. Unlike past research focusing on individual aspects of livelihood and farming systems individually, particularly either economic well-being or social aspects[32,36,37,39,40], this study examines the impact of COVID-19 on six dimensions of livelihood assets (financial, social, human, natural, physical, and psychological factors) combined, providing more robust findings. Additionally, this study specifically focuses on high-value crops, which are crucial for commercial farming, whereas other studies broadly focus on farming systems. Conducted in 2022, the study generates more robust, longer-term findings compared to studies conducted immediately after the outbreak of COVID-19 in 2020[2,18,19,32–36,39–42]. Finally, the use of Structural Equation Modeling (SEM) is employed in this study for research hypotheses testing since it is more robust than other studies using the OLS model or qualitative approaches[43]. The key methodological strength of this study is the application of first-order SEM to evaluate the impact of COVID-19 on livelihood assets. SEM enables the analysis of complex relationships between observed and latent variables, facilitating a more nuanced comprehension of the interrelations and impacts of various dimensions of livelihood assets during the pandemic.

As the global food systems have been significantly disrupted by the COVID-19 pandemic, which has resulted in intensified food insecurity, it is essential to comprehend the effects to develop strategies that will improve the sustainability and resilience of agricultural systems and livelihoods, particularly in developing countries such as Bangladesh. The study offers a comprehensive evaluation of the pandemic's effects on six dimensions of livelihood assets among high-value crop farmers, providing critical insights for policymakers to develop evidence-based recommendations for targeted interventions. This research provides critical insights into the multifaceted impacts of the COVID-19 pandemic on high-value crop producers in Bangladesh, thereby facilitating the creation of more sustainable and resilient food systems. The findings are especially pertinent for policymakers, as they offer evidence-based recommendations for targeted interventions that can improve the resilience of rural communities and ensure food security. This study contributes valuable knowledge to the existing body of research by addressing a research gap on the pandemic's impact on high-value crop producers.

The paper is divided into six sections. The literature review is presented in Section "Literature review", followed by the methodology in Section "Methodology". Section "Results" presents the results, whereas Section "Discussion" presents the discussion. Conclusions and policy recommendations are presented in the final section.

Literature review

In Bangladesh, approximately 16.2 million farm households, predominantly smallholders (with 0.05–2.49 acres of land), engage in commercial vegetable production, utilizing approximately 2.63% of the total cultivable land[44]. While the immediate consequences of COVID-19 were widely felt[21], on-farm challenges also emerged. Assessment of agricultural inputs became more difficult, leading to increased production costs alongside labor shortages and transportation hurdles. Farmers experienced obstacles in harvesting crops or transporting goods to markets due to mobility restrictions[22]. The reduced number of vehicles on the road contributed to heightened food transportation costs[23]. Labor shortages further hampered agricultural productivity, while travel restrictions constrained access to markets for both sellers and buyers[24]. Although there was a surplus of physical labor due to the return of migrant workers from other countries and unemployed urban workers to rural areas, restrictions on the movement of migrant workers resulted in labor shortage[25–27].

In addition to production issues, farmers encountered market challenges stemming from a decrease in consumer demand for goods, especially perishables. High-value agricultural products such as fruits and vegetables, meat, fish, milk, and eggs, which typically have strong income elasticities, experienced substantial declines in demand due to reduced earnings among non-salaried informal workers and price hikes, particularly in metropolitan areas[28]. As consumer demand dwindled, supply disruptions persisted, forcing farmers to sell below cost and leading to significant financial hardships[29].

These production disruptions are not unique to the COVID-19 pandemic but have been observed in both emerging and industrialized nations during previous epidemics. Diseases like Ebola, MERS, and SARS primarily disrupted food systems in the regions where they occurred[9]. By affecting agricultural labor forces and hindering other input factors[10], these diseases significantly reduced agricultural production[11]. Similarly, COVID-19 has had a profound impact on the agricultural production industry, which serves as the cornerstone of the food system.

The sustainable livelihoods approach offers a framework for understanding the purpose, significance, and dimensions of human development[12]. It encompasses various forms of capital, including natural, economic, financial, human, and social, all of which contribute to sustainable livelihoods. Natural capital refers to the ownership or shared management of natural resources such as climate, soil fertility, and water sources, which are essential for production[13]. Human capital encompasses all human potential that enables individuals to pursue various livelihood activities and achieve communal objectives[14]. Physical capital comprises infrastructure and means of production necessary to support livelihoods[15]. Social capital emerges from social organizations and encompasses characteristics like trust, norms, and collaboration, which can strengthen society by promoting coordination and cooperation for various benefits[16]. Financial assets indicate access to different resources, particularly savings and loans[17]. Both direct loans and savings serve as forms of productive capital that can be converted into other types of capital or utilized for immediate consumption.

COVID-19 had a profound impact on rural livelihoods, manifesting in several ways[19,20]. For example, many individuals lost their jobs due to regulations on social interactions, self-imposed isolation, and travel restrictions. Additionally, panic buying resulted in unpredictable food supplies. The significant disruptions to the agriculture industry led to severe food shortages, lower wages and significant food insecurity among Bangladesh's daily wage workers, who comprise one-third of the labor force[18]. Labour shortages affected agricultural production, while travel restrictions constrained access to markets for both buyers and sellers[24]. Consequently, prices for agricultural products initially surged in local marketplaces due to a lack of consumers and dealers before subsequently plummeting, particularly for perishable goods like vegetables and fish[42].

Previous research indicates that COVID-19 significantly disrupted households' ability to access adequate food, with 82.5% of respondents expressing concerns about food security, rising costs, and disruptions in local markets[36]. The pandemic also had adverse effects on agricultural production, sales, prices, and income, with over 80% of farms experiencing sales declines and 20% faced severe losses, while 90% reported price reductions[39]. The vulnerability of households to the COVID-19 outbreak encompasses social, economic, human, physical, and psychological dimensions, which significantly impact their resilience[40]. The diverse impacts of shocks on rural households highlight the disparities in their capital assets and subsistence strategies, influencing their ability to recover from market or natural shocks[45]. For rural households with limited access to natural resources, procuring food and accumulating other assets becomes challenging, exacerbating vulnerabilities[46]. Furthermore, the trauma experienced during crises can lead people to rely more heavily on their social networks for support[47]. Shocks such as epidemics can severely impact various livelihood assets (financial, social, human, physical, and natural assets), as evidenced by the negative effects of Ebola on home crop production in Liberia, exacerbating food insecurity[48]. While previous studies have addressed the impacts of epidemics and COVID-19 on individual aspects of livelihoods and farming systems, our research offers a comprehensive perspective by examining the combined vulnerability of six dimensions of livelihood assets (financial, social, human, physical, natural, and psychological assets). By including psychological assets our study acknowledges the holistic nature of livelihood vulnerability, recognizing that mental well-being influences and interacts with traditional livelihood assets. This comprehensive approach enables a more accurate assessment of the multifaceted impacts of COVID-19 on people's lives and livelihoods.

Methodology

Study area

The selection of the NW region of Bangladesh for this study was deliberate, considering its significant cultivation of high-value crops and prevalent poverty conditions, particularly exacerbated during the COVID-19 pandemic. Rural livelihoods in these regions rely heavily on high-value agriculture, making them vital study areas. Additionally, the NW region is susceptible to natural disasters, further complicating the socio-economic landscape. The pandemic exacerbated existing vulnerabilities, pushing households deeper into poverty[49]. The study focused on four districts within the NW region: Dinajpur, Rangpur, Bogura, and Pabna (see Fig. 1) chosen in collaboration with the Department of Agricultural Extension (DAE).

Data

The mWater surveyor app was used to conduct direct interviews using a structured questionnaire for the collection of primary data. A total of 320 farmers, 80 from each district, were surveyed from eight upazilas in four districts of the North-West region, employing a multistage sampling technique (Table 1). Initially, the selection of the four districts in our study was based on their prominence in high-value crop farming within the North-West region. In this study, two Upazilas were purposively selected from each district to capture the geographic and socioeconomic diversity within the districts, ensuring a comprehensive representation of different agricultural practices and livelihood conditions. Subsequently, farmers were randomly selected by drawing numbers from

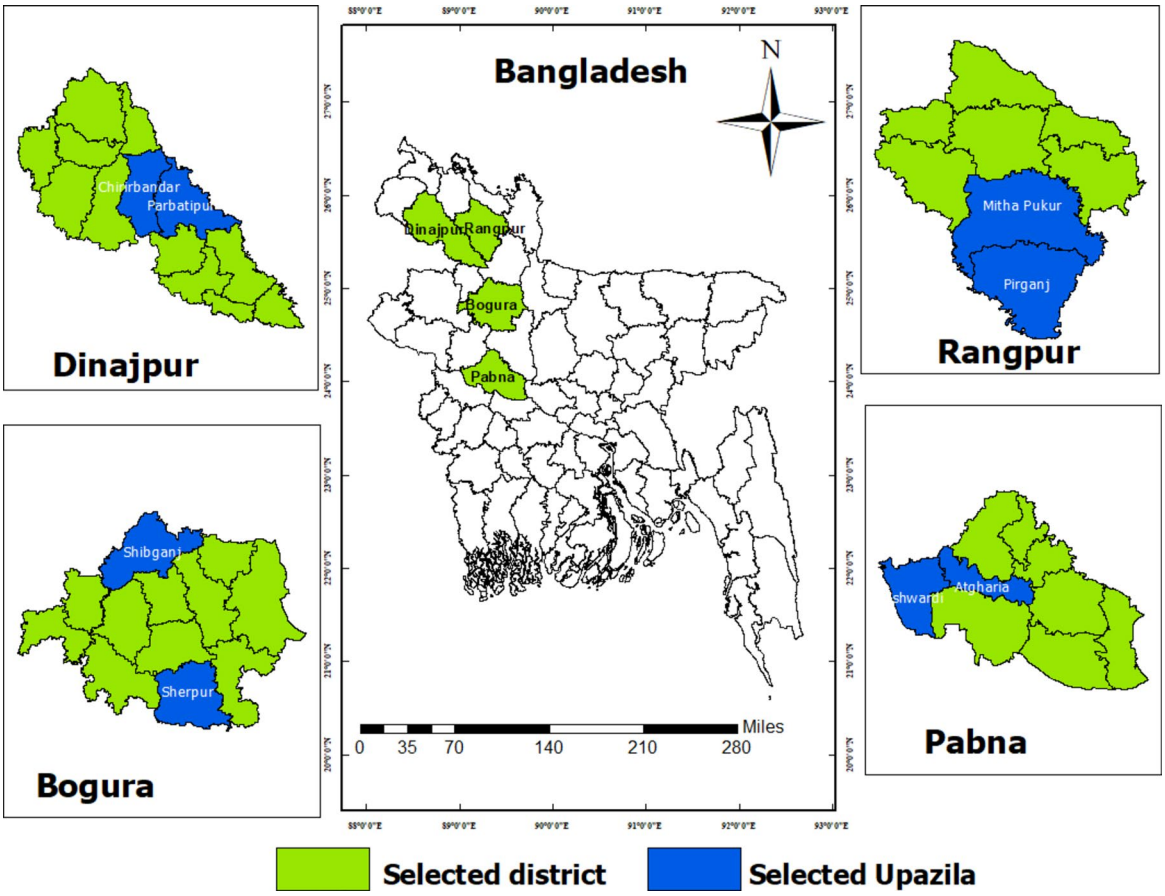

Fig. 1. Study area. The authors used ArcGIS 10.8 (https://www.arcgis.com/index.html) to produce the map, employing the administrative shapefile of Bangladesh in the process. Shapefile republished from the Bangladesh Agricultural Research Council (BARC) database (http://maps.barcapps.gov.bd/index.php) under a CC BY license, with permission from Computer and GIS unit, BARC, original copyright 2014.

Divisions	Districts	Upazilas	Sample size
Rajshahi	Bogura	Shibganj	40
		Sherpur	40
	Pabna	Ishwardi	40
		Atghoria	40
Rangpur	Rangpur	Pirganj	40
		Mithapukur	40
	Dinajpur	Parbatipur	40
		Chirirbandar	40
Total			320

Table 1. Study area and sample size.

a compiled list of high-value vegetable growers, provided by the Sub-Assistant Agricultural Officer of the DAE from the respective agricultural blocks. An equal sample size of 40 participants per Upazila was adopted to ensure statistical consistency and enable reliable comparative analysis across Upazilas, thereby enhancing the robustness of our findings.

The total sample size was determined using the following formula[50].

$$n = \frac{p \times (1-p) \times z^2}{e^2}$$

where p is the predicted proportion of respondents and n is the sample size, the p-value of 0.50 was utilized to obtain the greatest number of respondents. The acceptable margin of error is represented by e, which is equal to 0.06, and Z stands for standard error for a 95% confidence level. So, the sample size would be,

$$n = \frac{0.5 \times (1 - 0.5) \times 1.96^2}{e^2} = 266 \approx 320$$

Although the estimator suggested a sample size of 266, we selected to survey 320 farming households from four districts in Bangladesh to reduce the margin of error by an additional 20%. Farmers from the study area were selected using simple random sampling. These individuals, known as high-value agricultural producers, specialize in cultivating crops such as brinjal, pointed gourd, beans, cabbage, cauliflower, tomato, carrot, and bottle gourd.

The survey was conducted between May and June 2022, relying on respondents' memories for data for 2019 and 2022. This sample had been used previously somewhere else. A structured questionnaire was designed (as detailed in Supplementary file 2), covering demographic characteristics, livelihood assets, and psychological factors of high-value crop farming. Equal weight was given to each of the six livelihood diversification options when selecting responses. The questionnaire underwent pre-testing by the authors before being finalized. The study did not use the pre-tested data in the analysis. Data collection was conducted via face-to-face interviews using the finalised questionnaire, which was exported to the mWater portal, a web-based digital data collection tool.

Model

In this study, we examine the impact of COVID-19 on the assets of high-value crop farmers in Bangladesh's NW region using a reflecting model. Reflective models are applicable when indicators represent underlying latent constructs, meaning changes in the latent variable are mirrored in changes in the indicators[51]. The financial, social, physical, human, natural, and psychological resources examined in this study are considered reflective, as they are expected to adapt to changes in the underlying latent concept of livelihood impact.

The collected primary data were used to assess the impact of COVID-19 on livelihood assets. First-order partial least square structural equation modelling (PLS-SEM) was applied to determine these impacts using SmartPLS 4 software[52]. Structural equation modelling is a hypothesis testing method that evaluates whether the indicators accurately measure latent variables. As latent variables cannot be directly measured, they are inferred from the observable. Due to its flexibility in modelling complex interactions without making rigid assumptions about data distribution, PLS-SEM is well suited for this purpose. It is particularly useful for analyzing data from small samples providing valid findings[43].

Figure 2 presents the conceptual model linking the relationship between six livelihood factors and COVID-19 impacts. Twenty-seven statements were constructed to define six livelihood assets (see Appendix Table 1). The scales and attributes were derived from previous research[5], and these were tailored to the context of vulnerable livelihood assets in Bangladesh. Farmers responses to these statements were collected using a five-point Likert scale (1 = very low to 5 = very high). COVID-19 was treated as a dependent variable, categorised as 0 = before COVID-19 and 1 = during COVID-19. The study identified five categories of assets: natural, physical, financial, human, and social[6]. These assets play a vital role in survival strategies for rural and urban livelihoods[7]. Additionally, psychological assets, such as fear of infection, social tensions, and depression, were considered due to the pandemic's profound effect on mental health and well-being. The capacity of farmers to manage tension and anxiety became an integral component of their overall vulnerability. Psychological vulnerability (defined as PhAV) was added based on the COVID-19 pandemic when anxiety, worry, and depression were high among the farmers[53]. Financial assets were chosen as indicators to capture the pandemic's economic effects. Farmers were expected to experience income loss, increased food prices diminished purchasing power, and unemployment as a result of the pandemic. Financial asset vulnerabilities (FAV) indicate income loss, decreased purchasing power, increased food prices, unemployment, poverty, and inequality. Social resources that people utilize to support their livelihoods are referred to as social property because they are part of a network of social ties between individuals or groups[54]. Farmers frequently communicate face-to-face with friends and family members to demonstrate their skills and knowledge of agricultural operations[55]. Social assets were chosen as indicators due to their involvement in crisis resilience[56]. It was anticipated that the pandemic's impact on social interactions, trust in information sources, and social insecurity would hinder farmers' ability to respond to the crisis' challenges. Social asset vulnerability (SAV) encompasses trust among individuals, social solidarity, trust in media information, changes in traditions and customs, and social insecurity. Given the threat posed by the pandemic to public health, assessing the vulnerability of human assets becomes crucial. Anticipated outcomes of the pandemic, such as the closure of educational institutions, limited access to medical services, and psychological distress, could significantly impact high-value crop producers. Human assets vulnerability (HAV) is therefore characterised by factors such as the closure of educational institutions, inadequate access to medical staff, and insufficient health information and counselling services. Physical assets typically encompass essential amenities and infrastructure supporting agricultural production and livelihoods such as tractors, water supply canals, and roads. Disruptions in the supply chain caused by the COVID-19 pandemic have limited access to vital agricultural inputs and equipment. Understanding the pandemic's impact on agricultural productivity necessitates a thorough evaluation of physical assets vulnerability. (PAV), which includes factors like inadequate access to pharmaceutical items, limited availability of disinfectants and detergents, and a shortage of reliable resources providing information about COVID-19 treatment. Natural assets refer to the natural properties relied upon for survival and progress. Disruptions to farming operations, brought about by the pandemic, are of utmost importance, as they can significantly affect farmers' ability to sustain themselves. Natural assets vulnerability (NAV) encompasses delays in agricultural activities, underutilization of natural and recreational resources, decreased agricultural outputs, and farmers' hesitancy to plan crop production[55,57]. Detailed descriptions of these assets are provided in Appendix Table 1.

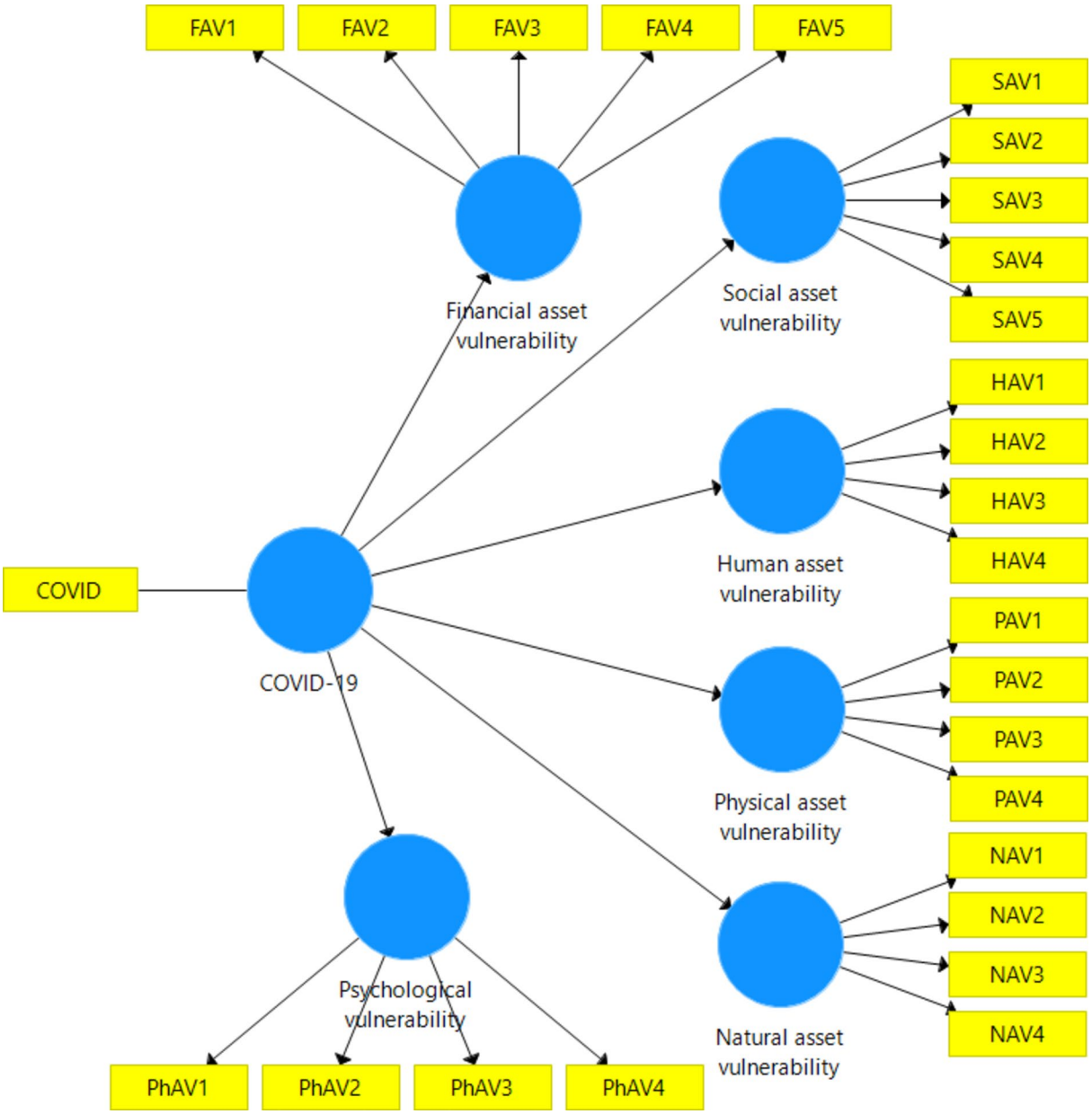

Fig. 2. A conceptual model.

To estimate the impacts of COVID-19 on different livelihood assets, we constructed and estimated the following six equations (Eqs. 1–6),

$$FAV = f(\text{The COVID - 19}) \tag{1}$$

$$SAV = f(\text{The COVID - 19}) \tag{2}$$

$$HAV = f(\text{The COVID - 19}) \tag{3}$$

$$PAV = f(\text{The COVID - 19}) \tag{4}$$

$$NAV = f(\text{The COVID - 19}) \tag{5}$$

$$PhAV = f(\text{The COVID - 19}) \tag{6}$$

These conceptual equations illustrate our aim to estimate the impacts of COVID-19 on various livelihood assets. The following six hypotheses were formulated to support the above six equations:

H_1 = The COVID-19 has a substantial impact on the vulnerability of financial assets.
H_2 = The COVID-19 has a substantial impact on the vulnerability of social assets.
H_3 = The COVID-19 has a substantial impact on the vulnerability of human assets.
H_4 = The COVID-19 has a substantial impact on the vulnerability of physical assets.
H_5 = The COVID-19 has a substantial impact on the vulnerability of natural assets.
H_6 = The COVID-19 has a substantial impact on the vulnerability of psychological assets.

As a result, three steps were taken to ensure the precision of the measurement model: (1) Model dependability and validity, (2) Uni-dimensionality, and (3) Diagnostic analysis, all of which were applied to the effect of COVID-19 on means of subsistence.

In assessing reliability, indicators are evaluated based on their consistency in measuring a particular component. When the construct explains more than 50% of the variation of the indicator, as is the case when loading is above 0.60, the indicator is said to have a satisfactory level of dependability[58]. When evaluating reliability, a higher score is better. Reliability levels that are "acceptable to good" are explained by results between 0.70 and 0.95. Next, the average extracted variance was used to determine the convergent validity (AVE). The AVE must be 0.50 or greater to be considered valid, meaning that the construct must account for (at least) 50% of the variance of its elements. Assessing the discriminant validity is the final stage. Finally, discriminant validity is assessed using Fornell–Larcker's criterion, which examines correlations between constructs. The suggested threshold is a value of the Fornell–Larcker criterion of 0.90.

Ethical approval

This study received approval from the Research Ethics Committee of Bangladesh Agricultural University, Mymensingh, Bangladesh (BAU-REC-2022-102) on April 20, 2022. The study was performed in accordance with the Declaration of Helsinki. Written informed consent was obtained from all participants and the questionnaires were anonymized to protect their privacy. Participants were also given the option to decline participation in the survey if they chose to do so.

Results

Socio-demographic characteristics of the respondents

Farmers' socio-demographic characteristics are explained in Table 2. The average age of the respondents during COVID-19 was 44.26 years. The mean household size was around five members. About 80% of farmers had various levels of literacy, ranging from primary to upper education. The results also demonstrate a decrease in the average total income of agricultural households during the pandemic. Specifically, the average income from vegetable cultivation decreased by 6,477 Taka, leading to reductions in expenditure. To cope with the income loss, farmers reduced their meals, resulting in an average reduction of 2,197 Taka in monthly household expenditure.

Each latent variable was operationalized through several indicators (as detailed in Appendix Table 1). Financial and social assets were represented by five indicators each; while natural assets had three indicators. Physical, human assets and psychological factors were represented by four indicators. The relationships between the latent variables and their respective indicators are presented in Table 3.

The findings revealed that the scores assigned to all assessed indicators of financial asset vulnerability ranged above three, indicating high to very high response. The pandemic had a significant income and purchasing power, leading to increased food prices, and reduced employment opportunities, and decreased incomes. Consequently, farmers had to reduce their expenditures by rationing basic needs such as food. The analysis also revealed a notable level of financial stress, as individuals had to ration food to accommodate other necessities.

An inverse relationship was found to exist between farmers' investments in social assets and vulnerability. Some highlighted outcomes included social distrust, particularly within communities and towards national information resources, erosion of social cohesion and solidarity, as well as heightened social vulnerability. Many

Variables	Before COVID (2019)		During COVID (2022)		Mean difference (2019–-2022)
	Mean ± SD	Percent	Mean ± SD	Percent	
Age (Years)	43.27 ± 0.75	–	44.26 ± 0.74	–	0.984
Family member (No.)	4.94 ± 1.71	–	4.94 ± 1.70	–	0.001
Education					
Primary (Dummy)	–	31.30	–	31.90	0.005
Secondary (Dummy)	–	28.80	–	28.70	− 0.001
Higher secondary and upper (Dummy)	–	20.70	–	20.60	− 0.001
Total monthly income (BDT)	25,430 ± 1129	–	18,953 ± 839	–	− 6477***
Total monthly expenditure (BDT)	16,365 ± 475	–	14,167 ± 425	–	− 2197***

Table 2. Descriptive and inference statistics of socio-demographic characteristics. Responses were collected during two distinct periods, and a t-test was employed to ascertain the statistical significance between the pre-COVID-19 and during-COVID-19 phases. ***$p < 0.01$, **$p < 0.05$, *$p < 0.10$. SD denotes standard deviation. 1 USD = 109.26 BDT.

Latent variable	Indicators	Mean	SD	Kurtosis	Skewness
COVID-19	COVID	0.500	0.500	− 2.006	0.000
Financial assets vulnerability (FAV)	FAV1	3.561	0.838	0.967	− 0.608
	FAV2	3.348	1.001	0.055	− 0.563
	FAV3	3.319	0.982	0.054	− 0.544
	FAV4	3.202	1.012	− 0.126	− 0.557
	FAV5	3.494	0.848	0.550	− 0.489
Social assets vulnerability (SAV)	SAV1	2.998	1.010	− 0.503	− 0.289
	SAV2	2.986	0.959	− 0.424	− 0.376
	SAV3	2.292	1.086	− 0.492	0.546
	SAV4	3.278	1.037	− 0.269	− 0.433
	SAV5	2.717	1.095	− 0.932	− 0.109
Human assets vulnerability (HAV)	HAV1	4.003	0.737	− 0.197	− 0.263
	HAV2	3.131	1.054	− 0.408	− 0.465
	HAV3	2.822	1.071	− 0.877	− 0.268
	HAV4	2.925	1.062	− 0.729	− 0.336
Physical assets vulnerability (PAV)	PAV1	2.620	1.157	− 1.092	0.048
	PAV2	2.734	1.162	− 1.037	− 0.045
	PAV3	2.673	1.089	− 1.048	− 0.118
	PAV4	2.708	1.089	− 1.008	− 0.136
Natural assets vulnerability (NAV)	NAV1	2.181	1.063	− 0.815	0.487
	NAV2	2.895	1.029	− 0.621	− 0.134
	NAV4	2.352	1.058	− 0.882	0.294
Psychological factors vulnerability (PhAV)	PhAV1	3.248	1.108	− 0.337	− 0.544
	PhAV2	3.255	1.006	− 0.074	− 0.527
	PhAV3	3.056	1.043	− 0.468	− 0.386
	PhAV4	3.427	1.046	0.066	− 0.642

Table 3. Descriptive statistics of the livelihood assets vulnerability.

of these changes were attributed to social distancing measures and restrictions on gatherings, which hindered relationships that typically offer social support.

Overall, human assets remained more vulnerable in specific areas, including education and health sectors. School closings disrupted children's education and hindered the long-term development of human capital. Additionally, inadequate access to medical services and health information complicated households' ability to manage their health during the pandemic. Health concerns and mobility limitations also reduced labour availability, leading to lower agricultural output.

Farmers faced significant challenges in obtaining essential goods and/or services such as disinfectants, sanitary products, and medications. Delays in planting and harvesting were common due to labour shortages and movement restrictions. Market access was also restricted, affected the physical transportation of goods, which further strained physical resources.

Another example of the vulnerability of natural assets was seen in the postponement of the farming seasons, resulting in reduced production and efficiency. Farmers hesitated to invest in the next planting season due to uncertainty. Input constraints and limited extension services, crucial for managing natural resources, resulted in inefficient use of the resources.

The study also demonstrated that farmers experienced adverse effects on their psychological health due to the COVID-19 outbreak. The uncertainty and health risks posed by the epidemic increased the prevalence of depression and anxiety. Farmers grappled with the social and economic consequences, which led to heightened social tensions and frustrations. Coping strategies, including reduced food intake and increased reliance on social support networks, were employed to deal with the stress of revenue loss and changed behaviours.

Confirmatory factor analysis (CFA)

The structure of factors was assessed using CFA, which relied on factor loadings to test the validity of the factors. The threshold values for combined reliability, Cronbach's α coefficient, and average extracted variance for each structure in the intended model were greater than 0.60, 0.70, and 0.50, respectively. The reliability and validity of all the latent variables are shown in Table 4.

We found that the factor loading values of SAV3 and HAV1 were less than 0.70. Given that the factor loadings did not exceed the cut-off, this suggests that these two factors were invalid. Besides, the coefficient of determination (CR) and Cronbach α were used to determine the latent constructs' reliability. Thus, the measurement model findings show that for all the latent variables, the least value of Cronbach's alpha and CR was larger than 0.70.

Latent variable	Indicators (Details in Appendix Table 1)	Factor loadings > 0.60	Cronbachs' Alpha (CBA), 0.70–0.90	Composite reliability (CR), > 0.70	Average variance (AVE), > 0.50	R^2	Adjusted R^2
FAV	FAV1	0.837*** (0.024)	0.836	0.884	0.603	0.496	0.495
	FAV2	0.704*** (0.032)					
	FAV3	0.747*** (0.029)					
	FAV4	0.687*** (0.033)					
	FAV5	0.813*** (0.024)					
SAV	SAV1	0.828*** (0.021)	0.728	0.831	0.554	0.466	0.465
	SAV2	0.693*** (0.031)					
	SAV3	0.710*** (0.032)					
	SAV4	0.727*** (0.029)					
	SAV5	0.693*** (0.036)					
HAV	HAV1	0.847*** (0.024)	0.864	0.917	0.787	0.542	0.541
	HAV2	0.659*** (0.037)					
	HAV3	0.853*** (0.027)					
	HAV4	0.774*** (0.034)					
PAV	PAV1	0.677*** (0.041)	0.801	0.870	0.627	0.293	0.292
	PAV2	0.832*** (0.030)					
	PAV3	0.603*** (0.053)					
	PAV4	0.829*** (0.032)					
NAV	NAV1	0.849*** (0.035)	0.768	0.800	0.501	0.358	0.357
	NAV2	0.875*** (0.029)					
	NAV4	0.644*** (0.034)					
PhAV	PhAV1	0.708*** (0.032)	0.865	0.908	0.712	0.286	0.285
	PhAV2	0.621*** (0.034)					
	PhAV3	0.743*** (0.028)					
	PhAV4	0.684*** (0.031)					

Table 4. The conceptions and indicators' convergent validity and reliability. Threshold of factor loading > 0.60, CBA > 0.70–0.90, CR > 0.70, and AVE > 0.50. The figure in the parentheses indicates the standard deviation.

Furthermore, all AVE values were above 0.50, indicating convergent validity. After excluding the two invalid factors (SAV3 and HAV1), the convergent validity and reliability were re-estimated.

Since all the factor loadings exceeded the cut-off, we concluded that none of the factors were invalid (Table 4). Therefore, the results of the measurement model indicate that all the minimum values of Cronbach's α and CR were greater than 0.70, suggesting that all the constructs were statistically reliable. The relationship between the variables is instead determined using convergent validity[59]. Convergent validity was assessed using the same study, which gave the AVE threshold of 0.50. As the lowest validity was determined to be 0.561, which exceeded 0.50, the results suggest that all the latent constructs have acceptable convergent validity.

The predictive value of the model was assessed using the R-square value. The R-square values indicate that the variance in COVID-19 explained 49.6%, 46.6%, 54.2%, 29.3%, 35.8%, and 28.6% in financial, social, human, physical, natural, and psychological assets vulnerability, respectively.

Assessment of discriminant validity

The Fornell–Larcker criterion was applied to evaluate discriminant validity by establishing the degree to which one latent concept is distinguishable from the other. The study claimed that 0.90 is the highest figure appropriate in this case. Consequently, none of the connections had a value greater than 0.90 (Table 5), showing that no violation of the discriminant validity assumption occurred.

Path coefficient assessment

The study utilised bootstrapping (5,000 iterations), a resampling approach, to assess the importance of each component in explaining the others. The path coefficient results are presented in Table 6.

We find that the impact of COVID-19 on all livelihood assets was statistically significant at 1% (Table 6). Figure 1 in the appendix presents the outcomes of the path model. All latent variables were significantly affected by COVID-19 (financial assets, social assets, human assets, physical assets, natural assets, and psychological factors). The p-values and standardized regression coefficients are presented in the numbers on the path relationships. The p-values were less than 0.01 for all latent variables, indicating significance at the 1% level. On the other hand, the values from latent variables to indicators imply the relationship between indicators and latent variables. For all the indicators, the p-values were less than 0.01, indicating significance at the 1% level. This suggests that all the indicators were related to the latent variables.

We discovered that COVID-19 had the greatest effect on financial assets (coefficient = 0.709; p-value < 0.01). The positive effect indicates that income and purchasing power were reduced by the COVID-19 pandemic due to

Livelihood vulnerability constructs	COVID-19	Financial asset	Human asset	Natural asset	Physical asset	Psychological factors	Social asset
COVID-19	1						
Financial asset	0.704						
Human asset	0.736	0.645					
Natural asset	0.598	0.659	0.582				
Physical asset	0.541	0.542	0.69	0.54			
Psychological asset	0.535	0.558	0.538	0.516	0.384		
Social asset	0.682	0.704	0.685	0.701	0.543	0.606	1

Table 5. Assessment of discriminant validity (Fornell–Larcker criterion).

Hypotheses	Path	Path coefficient	Confidence interval at 95%	Decisions about hypothesis
H_1	COVID-19→FAV	0.709*** (0.019)	0.670–0.733	Accepted
H_2	COVID-19→HAV	0.740*** (0.015)	0.710–0.761	Accepted
H_3	COVID-19→NAV	0.600*** (0.023)	0.560–0.635	Accepted
H_4	COVID-19→PAV	0.542*** (0.025)	0.494–0.577	Accepted
H_5	COVID-19→PhAV	0.537*** (0.028)	0.484–0.577	Accepted
H_6	COVID-19→SAV	0.684*** (0.019)	0.647–0.711	Accepted

Table 6. Path coefficient and hypothesis decision. ***Indicates significance at a 1% probability level. The figure in the parentheses indicates the standard deviation.

inflated food prices, decreased employment opportunities, and increased costs of rural households. Additionally, COVID-19 had a statistically significant and positive effect on social assets (coefficient = 0.684, p-value < 0.01), indicating that due to the COVID-19 pandemic, people's trust in each other declined, social solidarity diminished, and the level of social insecurity increased. The lowest impact of COVID-19 was on human assets (coefficient = 0.740, p-value < 0.01), which implies the COVID-19 pandemic forced educational institutions to close, there was a lack of adequate health information and a lack of adequate medical staff. COVID-19 affected physical assets significantly and positively (coefficient = 0.542, p-value < 0.01), showing that the COVID-19 pandemic reduced sufficient access to pharmaceutical items, disinfectants, sanitary detergents, and reliable medical information. Furthermore, COVID-19 had a statistically significant and favourable influence on natural assets (coefficient = 0.600, p-value < 0.01), indicating that due to the COVID-19 pandemic, farming activities (fertilization, harvesting etc.) were delayed, agricultural output decreased, and farmers were reluctant to plan to grow their crops. COVID-19 also had a significant and positive impact on psychological factors (coefficient = 0.537, p-value < 0.01), indicating that due to the COVID-19 pandemic, farmers were worried about getting COVID-19, social tensions were high, and depression and disappointment increased. The impact of COVID-19 was less on physical assets and psychological assets compared to other assets.

Discussion

The impact of COVID-19 on assets used for sustaining livelihoods has been thoroughly examined. According to the path analysis, COVID-19 had a substantial influence on all categories, including financial, social, physical, human, natural, and psychological assets. This is consistent with most earlier studies, which have also observed a strong influence of COVID-19 on rural livelihoods[5]. Figure 3 illustrates the significant impact of COVID-19 on the assets supporting the livelihoods of farmers engaged in high-value agriculture in the NW regions of Bangladesh.

The COVID-19 pandemic has been found to have a statistically significant and considerable effect on the vulnerability of financial assets within the high-value crop farming sector. According to our findings, 91.3% of farmers believed that the COVID-19 pandemic had decreased income and purchasing power in rural households. Similar results were reported by Kundu et al.[34]. Additionally, around 78% of farmers concurred that the pandemic had led to an increase in food prices[60]. This rise in food costs forced many farmers to go without eating, contributing to widespread malnutrition. Moreover, approximately, 77.5% of farmers stated that rural household employment had decreased due to the pandemic, a trend confirmed by Mandal et al.[61]. Many rural residents feared that poverty and inequality would worsen if the pandemic persisted, with 86.3% of farmers holding this view[62]. Additionally, about 71% of farmers believed that the COVID-19 epidemic was responsible for rising living expenses[63]. These findings highlight the tangible negative impact of the pandemic on the economic dimensions of the farmers' livelihoods. Farmers faced a decline in income, a reduction in their ability to purchase goods and services, and an increased susceptibility to financial risks, attributed to factors such as escalation of food prices and disruptions in the economy.

School dropout became a significant challenge in Bangladesh during the COVID-19 pandemic due to various factors, including limited internet access in rural areas, a lack of electronic devices, high costs of internet, early

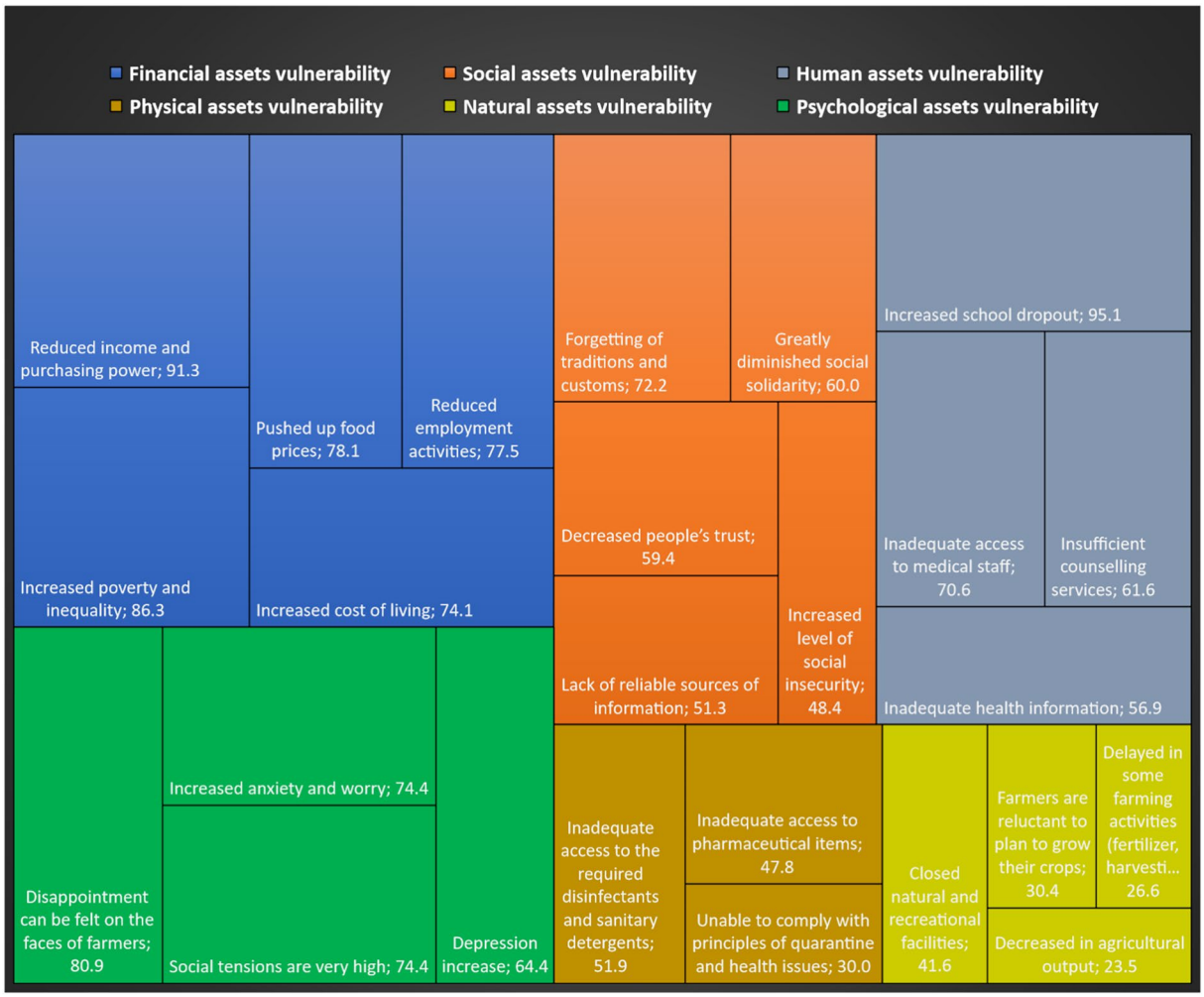

Fig. 3. TreeMap illustrates the consequences of COVID-19 on six livelihood domains. Note: The number in the figure shows the percentage of farmers who 'agreed' to 'strongly agreed' with the statement.

marriage and maternal age, prolonged closures of educational institutions, and inadequate teacher preparation for online learning[64]. Over 95% of farmers agreed that the pandemic had contributed to increased school dropout rates due to limited access to educational facilities[65]. Additionally, 70.6% of farmers agreed that the scarcity of medical personnel and lack of healthcare information in rural areas had heightened the risk of COVID-19 infection[66]. These findings suggest that the pandemic had significant implications for both the physical and mental well-being of farmers. The closure of educational institutions, limited access to medical services, and heightened psychological distress underscored the diverse impact on human and psychological resources.

The COVID-19 pandemic has significantly affected social assets, with evidence pointing to decreased social solidarity (60%), reduced social trust (59.4%), and increased social insecurity (48.4%), findings that align with those of De Vos[9]. Furthermore, a majority of farmers (80.9%) reported heightened vulnerability to psychological disorders, such as anxiety, stress, and disappointment[67]. These observations highlight the profound impact of the pandemic on the social fabric and mental health of farmers. Challenges in maintaining social bonds, accessing reliable information sources, and managing escalating social tensions and feelings of insecurity have become prevalent. This underscores the societal and psychological consequences of the pandemic on individuals' livelihoods.

Approximately 26.6% of farmers acknowledged that various agricultural activities, such as harvesting and fertilizing, were disrupted during the COVID-19 pandemic[68]. Additionally, around 30% of farmers agreed that the rural community struggled to fully comply with quarantine and health standards due to existing facilities and physical layout constraints[69]. As a result, agricultural production declined (23.5% responses), and farmers hesitated to plan future crop cultivation (30.4% responses)[70]. These findings underscore the pandemic's adverse effects on agricultural productivity, as farmers encountered difficulties accessing essential inputs and infrastructure[37]. This highlights the pressing challenges in safeguarding physical and natural assets amid the crisis.

Our results align with previous research highlighting the significant impact of COVID-19 on rural livelihoods. Consistent with Kundu et al.[34] we observed a decrease in income and purchasing power among rural households. Similarly, our findings of rising food prices and resulting malnutrition corroborate those of Rabbi et al.[60]. However, our study identifies distinct causal factors contributing to these impacts. Disruptions of supply

chains and reduced labor availability due to mobility restrictions directly affected agricultural productivity and income. Moreover, financial vulnerabilities were compounded by issues with market access, highlighting the interdependent nature of these factors. By focusing on high-value crop farmers, our study provides new insights into specific vulnerabilities within this subgroup, despite the overall consistency with existing research.

In a nutshell, the COVID-19 pandemic has had a profound impact on the ability of individuals to maintain their livelihoods, ranging from significant to extreme. The confirmation of all hypotheses underscores the extensive influence of the pandemic on various aspects of high-value crop farmers' livelihoods. Given the heterogeneous nature of these impacts, policymakers must be mindful and develop pro-poor strategies to enhance crisis-resilience capacity, particularly targeting the most vulnerable farm households in Bangladesh.

Practical implications

While it is true that the government of Bangladesh has taken proactive measures to address the challenges posed by COVID-19 in the agricultural sector[2,71], it is important to note that the situation remains dynamic. Ongoing research can play a vital role in shaping policy-making in several ways. The broad impact of COVID-19 on farmers' livelihoods highlights the need for comprehensive, multifaceted policy interventions. By addressing the specific vulnerabilities and underlying causes identified in this study, policymakers can bolster the resilience of rural livelihoods against future crises.

Firstly, our current research provides a comprehensive and in-depth analysis of the impact of COVID-19 on livelihood assets, specifically focusing on high-value crop farmers. By quantifying the extent of the pandemic's impact on various assets related to vulnerability, such as human, financial, social, natural, physical, and psychological, our study offers a nuanced understanding of the lingering effects that may not have been fully addressed yet. Secondly, while the government has prioritized the cultivation and export of high-value vegetables[42,72], our research can identify gaps in these policies and shed light on potential vulnerabilities that might still exist within the sector. For instance, our findings highlight the significance of different asset categories, with financial assets being the most impacted. This emphasizes the need for targeted interventions and support mechanisms, such as access to low-interest loans or financial aid, which can further strengthen the resilience of high-value crop farmers. On the other hand, to enhance the accessibility of healthcare and education services in rural areas, policymakers must prioritize investments in digital infrastructure. The healthcare infrastructure must be fortified to mitigate the psychological distress and health risks that producers encounter. Local governance structures and community-based organizations should be instrumental in the development of trust and social cohesion. Furthermore, our research underscores the role of mobility restrictions and lockdowns as factors affecting livelihoods. As these measures could potentially recur in response to various shocks, including new variants or future pandemics, our study offers insights into strategies that can minimize disruptions. Proposing the establishment of a well-structured online marketplace for agricultural products and exploring labor-efficient farming techniques could mitigate the negative consequences of movement restrictions.

In summary, while initial policy responses have been implemented, our current research contributes by providing a comprehensive analysis of the multifaceted impact of COVID-19 on high-value crop farmers' livelihoods. By identifying areas of vulnerability and proposing targeted strategies to enhance resilience, our findings can assist policymakers in refining and adapting their approach to ensure the long-term sustainability of this vital sector in the face of evolving challenges.

Conclusion, policy recommendations, and limitations

The study's findings revealed a significant impact of COVID-19 on all categories of assets crucial for sustaining livelihoods. The pandemic and associated governmental restrictions notably affected rural Bangladeshi livelihoods, primarily stemming from lockdowns, mobility limitations, and the repercussions of lost income, rising food prices, and diminished purchasing power. Farm households in a developing country like Bangladesh encounter multifaceted challenges. The unpredictable nature of the COVID-19 situation led to major disruptions in production and marketing activities, income reduction, increase in food prices, and job losses among high-value crop farmers, exacerbating long-term vulnerability.

The impact of COVID-19 on financial assets has been profound, creating economic pressure and disrupted the livelihood conditions of farmers. Urgent policy considerations are essential for their recovery. The interdependence of economic, institutional, and social ties within food systems underscores the need for comprehensive interventions. Movement restrictions during the pandemic severely curtailed farmers' access to markets, necessitating the development of a robust online marketplace to mitigate such disruptions, especially considering the perishable nature of agricultural commodities. To address the decrease in both farm and off-farm income and the rise in family expenditure, farmers require easy access to low-interest loans. Government input assistance programs should prioritise agribusiness production, incorporating labor-saving farming techniques and productivity-boosting technologies. Access to food, both physically and financially, is crucial, particularly during public health emergencies. This study underscores the importance of expanding direct cash transfer and food assistance programs and allocating resources to remove barriers to accessing food and other necessities, both in the present and the future.

While this study provides insights into the impact of the COVID-19 pandemic on farming households, it is important to acknowledge its limitations. One significant limitation is the reliance on respondents' memory due to the lack of written documentation regarding income, expenditure, and savings. This reliance on the recall method introduces potential recall bias and may affect the accuracy of the data collected. Additionally, the focus on high-value agricultural practices may limit the generalizability of findings to other social strata within farming communities. Furthermore, the study's cross-sectional design presents challenges in drawing definitive conclusions about changes in livelihoods over time. Further research could benefit from longitudinal studies to track

changes in high-value crop farming livelihood activities more accurately. Moreover, comparative analyses across different socio-economic strata would enhance our understanding of the differential impacts of the pandemic and the effectiveness of various policy interventions and adaptation strategies. This would provide valuable insights for policymakers seeking to mitigate the pandemic's effects on farming communities in developing countries.

Data availability

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

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Author contributions

U.S.: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper. M.J.A.; I.A.B.: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper. M.A.R.S.; T.J.; T.M.: Conceived and designed the experiments; Contributed reagents, materials, analysis tools, or data; Wrote the paper. M.S.P.; A.M.M.; A.K.: Analyzed and interpreted the data; Wrote the paper.

Competing interests
The authors declare no competing interests.

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