Examining Factors Determining Risks and Uncertainties in Crop Agriculture of Southern Bangladesh: A Principal Component Analysis

Md. Yahia Bapari
Assistant Professor, Department of Economics, Pabna University of Science and Technology, Pabna-6600, Bangladesh. Email: yahia.bapari@pust.ac.bd.

Dr. Md. Elias Hossain
Professor, Department of Economics, University of Rajshahi, Bangladesh. Email: eliaseco@ru.ac.bd.

Dr. Mir Khaled Iqbal Chowdhury
Professor, Department of Economics, Pabna University of Science and Technology, Pabna-6600, Bangladesh. Email: khalediqbal@pust.ac.bd.

***Corresponding Author: Md. Yahia Bapari;**
*Assistant Professor, Department of Economics, Pabna University of Science and Technology, Pabna-6600, Bangladesh. Email: yahia.bapari@pust.ac.bd.

Abstract
The present study examined various factors contributing to the risks and uncertainties associated with crop production in Bangladesh agriculture, using a principal component analysis with an orthogonal rotation method. A comprehensive survey involved four hundred farm households selected through multistage random sampling procedure from five districts in Bangladesh. Required data was collected from the chosen respondents using semi-structured questionnaires and administering face-to-face interviews. The survey revealed fifty-five risk factors and ten uncertainties, varying across districts due to climate variability, farmers' socioeconomic standing, vulnerable infrastructures, soil properties, pest and disease outbreaks, and government policies. Results showed that the risk factor analysis identified twelve principal components, with fifty-two individual factors and three removed based on cut-off thresholds, categorized as input, production, climate change, personal, farm, financial, socio-economic, market, investment, policy, political risk, and others. Uncertainty factor analysis identified four principal uncertainties, such as input, yield, pricing, and agricultural policy and global preference uncertainty, which covered ten uncertainties affecting cropping culture within the study area. The Cronbach's Alpha reliability test eliminated twelve and fourth principal component of risk and uncertainty whereas validity test invalid market, investment, political and other risks but allowed all principal uncertainties. Therefore, we obtained eight principal risks and three principal uncertainties, expressing reliable and valid factors within the study area. The study recommends measures to mitigate these risks, including diversification of crops, crop insurance, diversifying income sources, developing market linkages, improving access to credit and financial services, adopting technology, implementing climate-smart agriculture practices, seeking government support, selecting crops based on local conditions, and managing irrigation. These strategies can help farmers manage risks, increase resilience, and enhance agricultural productivity.

Keywords: Risks; Uncertainties; Crop Agriculture; Bangladesh; Principal Component Analysis.

1. Introduction

The risks and uncertainties that are associated with agricultural production operations were first encountered when farm households began to cultivate and harvest a smaller yield than they had hoped for. Crop production, being a biological process, heavily depends on various agro-climatic conditions. In developing countries, particularly in Bangladesh, crop agriculture is a highly risky and complex business (Bairwa et al., 2016; Begum et al., 2003; Komarek et al., 2020) and farming practices are vulnerable to hazards due to the unstable economic and biophysical environment in which cropping takes place (Ullah et al., 2016a). These risks and uncertainties threaten farmers' livelihoods and earnings (Drollette, 2009; Kuzman et al., 2017; Panda et al., 2012b), as well as undermining agricultural viability (Alizadeh-Masoodian & Nomikos, 2005; Raju et al., 2008).

Crop agriculture is influenced by various sources of risk and uncertainty, making it a challenging profession for farmers. Farmers are constantly exposed to a wide range of challenges, such as personal illness and unpredictable weather in pre-modern economy (Eggertsson, 1998). Technological, biological, and environmental factors pose significant risks to farms, resulting in reduced yields when not properly monitored and managed (Liliane & Charles, 2020). Globally, major increases in crop yields with significant variations are primarily due to technological developments, infrastructure improvement, and increased investment, such as increases in fertilizer investment (Fan et al., 2002). Conversely, climate disasters are the leading cause of variations in production (Fan et al., 2002; Li et al., 2009), with drought being one of the most widespread climate disasters affecting agricultural production worldwide (Dilley, 2005; Helmer & Hilhorst, 2006). Following drought, fungal infections of leaves, roots, and tuber crops are made more likely by the floods (Li et al., 2009).

Uncertain scenarios in crop production result in losses in agricultural revenue and crop misallocation for rural farmers (Godefroy & Lewis, 2018). It arises in developing countries' agriculture due to heavily changes in yield, product and input prices, technological advancements, global warming surge, and volatile global preferences (Adnan et al., 2020; Baliga & Tambad, 1964; M. S. Hossain et al., 2018; Liliane & Charles, 2020; Panda et al., 2012b; Quddus & Kropp, 2020; Ullah et al., 2016b). Experts believe that risk is a consequence of uncertainties that affect an individual's welfare and is often associated with adversity and loss in field crops (Harwood et al., 1999). However, not all uncertainties have a negative impact on agriculture. Crop productivity has been increased through numerous technological advancements in agriculture, including selective breeding, fertilizer technology, adaptive microbial technology, pesticides, farm machinery, and agronomic and management practices like integrated pest and nutrient management (Liliane & Charles, 2020).

Bangladesh is known to be one of the most susceptible countries in the world to the impacts of climate risks and natural disasters (Agrawala et al., 2003; M. S. Hossain, Qian, et al., 2019). Due to its geographical layout, the country experiences regular severe floods. The floods of 1974, 1984, 1987, 1988, 1991, and 1998 were particularly devastating, resulting in loss of human lives and severe damage to agricultural production (Agrawala et al., 2003). These events have caused a loss of 3,295 lives and have destroyed approximately 1.5 million households and 2.2 million hectares of cropland (M. S. Hossain, Qian, et al., 2019). Additionally, the country is also prone to heavy monsoon rains, cyclones, floods, storm surges, etc. due to its location between the funnel-shaped Bay of Bengal and the Himalayas (Ferdous & Baten, 2011). As a result, risks and uncertainties have long been acknowledged as a significant problem in the agriculture sector of Bangladesh, which calls for addressing crucial factors of cross-cutting issues (Panda et al., 2012b), and implementing multiple approaches to managing them (Miller, 2008).

2. Literature Review and Knowledge Gap

The 21st century has brought about a plethora of risks and uncertainties for agriculture, as evidenced by the agro-vulnerability experienced by farmers. These include floods, cyclones, drought, densely frost, CO_2 fertilization, pest infestations, death and illness of animals and poultry, policy shocks including changes in agricultural and environmental tax policies, and social, institutional and animal laws, shifting consumer preferences, global warming surge, imperfect markets and technological advancement (Adnan et al., 2020; M. S. Hossain et al., 2018; Liliane & Charles, 2020; Panda et al., 2012b; Quddus & Kropp, 2020; Ullah et al., 2016b). A plethora of studies have been conducted by experts to understand the sources of these threats, their forms, how they impact farming and farmers' livelihoods, and potential countermeasures. A significant number of these studies have focused on the factors of risk and uncertainty both domestically (Adnan et al., 2018; Ahsan, 2011; Alam & Guttormsen, 2019; Amin et al., 2014; M. S. Hossain et al., 2018; M. S. Hossain, Arshad, et al., 2019; M. S. Hossain & Majumder, 2018; Kabir et al., 2017; Pervez et al., 2016; A. Rahman et al., 2020; A. Sarker et al., 2021; Sikder & Xiaoying, 2014; Tibig & Lansigan, 2007) and internationally (Aimin, 2010; Backus et al., 1997; Benhin, 2008; Blanc, 2012; Donye & Ani, 2012; English, 1981; Ghadim et al., 2005; Hardaker, 1982; Kabubo-Mariara & Karanja, 2007; Koesling* et al., 2004; Panda et al., 2012a; Raj & Thomas, 2022; Roumasset et al., 1979; Seo & Mendelsohn, 2008; Ullah et al., 2016b; Zaporozhtseva et al., 2019).

The determinants of agricultural risks and uncertainties have been separately examined by (Harwood et al., 1999), who distinguish between risk, arising from various threats such as fluctuations in cost and output, natural disasters, and epidemics, and uncertainty, stemming from climate variability and market variations within the agricultural sector. (Moschini & Hennessy, 2001) place a particular emphasis on uncertainty, treating risk as a consequence thereof, and categorizing uncertainties into four main types: production, price, technology, and policy uncertainties.

Recent studies have acknowledged that threats from climate change, economic uncertainty, globalization, and political unpredictability have become increasingly evident and severe over time (Barrett & Constas, 2014; Darnhofer et al., 2016; Hansen et al., 2019). There is a conflicting and context-dependent body of quantitative data, particularly regarding weather and commodity prices, leaving the question of whether farmers' exposure to dangers in general has increased over time or not unanswered (Gilbert & Morgan, 2010; Rajeevan et al., 2008; Wildemeersch et al., 2015).

Geographic location, farm type, institutional structures, and other factors that influence the operating environment of farmers have been found to affect farmers' perceptions of risk and risk management (Boggess et al., 1985; Meuwissen et al., 2001; Patrick & Musser, 1997; Wilson et al., 1993). Income variability, weather, volatile commodity prices, changes in government laws and regulations, input costs, severe drought, rainfall variability, structural barriers to gender equality, such as access to land, increasing feed costs, extreme weather, and delays in veterinary treatment have been identified as risk factors for crop, dairy, and livestock farming (Chand et al., 2018; Flaten et al., 2005; Glemarec, 2017; Visagie & Ghebretsadik, 2005). Despite these findings, unanticipated events with significant impacts on farmers continue to occur, indicating that the nature of risk has evolved over time (Just, 2001). Factors such as a rising global population, changing dietary preferences, an uptick in the demand for animal-based foods, and climate change have made risk management more crucial than ever before in the agricultural business (Komarek et al., 2020).

Risk is a ubiquitous aspect of all agricultural management decisions, stemming from various sources of uncertainty. As farmers possess distinct preferences with respect to risk (Toledo et al., 2011), the choices made by crop growers are conditioned to a greater or lesser extent by a risk-minimizing process (Gómez-Limón et al., 2003). (Agarwal, 1964) posits that risk and uncertainty cannot be empirically differentiated from one another and that they constitute a twin problem in the context of Indian agriculture. He cites examples of risks and uncertainties in the form of production deviations caused by natural disasters, market fluctuations, technological advances, the actions of individuals, businesses, and government agencies with whom farmers interact, and unfavorable outcomes that farmers are not accustomed to. (L. W. Nieuwoudt, 1972) reached similar conclusions to (Agarwal, 1964) but based his findings on geographical differentials.

Nature-based agriculture is a primary source of risks and uncertainties. (Liliane & Charles, 2020) identify environmental factors such as abiotic stresses, including soil properties and climatic stresses, and biotic factors such as beneficial organisms, pests, and anthropogenic evolution, as posing high levels of risk in agriculture. These factors cause a host of morphological, physiological, biochemical, and molecular alterations in plants and detrimental effects on growth and productivity.

These global concerns have received significant attention from domestic researchers. (Ahsan, 2011) notes that agriculture is the primary driver of Bangladesh's economy, but numerous risks, including natural and man-made catastrophes as well as climate change, pose significant challenges to the sector's growth. This call to action has been acknowledged by some researchers, such as (Rahaman et al., 2018) who analyzed the perceptions of risk associated with pesticide use by rice farmers using a direct observation method and found that most farmers had an understanding of natural enemies of rice pests and that the application of synthetic insecticides in the field can reduce their population. Moreover, a group of researchers, namely (Z. Ahmed et al., 2021; M. S. Hossain et al., 2018) have shown interest in climate change risks and crop farming cultures.

There is a broad consensus that the use of chemical fertilizers, pesticides, and other products of modern agriculture is responsible for water pollution, the decline of biodiversity, and the degradation of soil quality brought on by intensified farming (Pretty, 1995). However, the most serious environmental issues in resource-poor locations, such as soil deterioration, chemical resistance in pests, and unfavorable weather, can also have a detrimental impact on agricultural production systems (Clapham, 1980). Farmers' productivity is influenced not only by the tools and equipment at their disposal, but also by the state of the environment in which they work (S. Rahman & Hasan, 2008). Researchers (M. A. R. Sarker et al., 2012) demonstrated that three different types of rice were significantly affected by maximum and minimum temperatures and rainfall.

The multifaceted impact of climate change on agricultural productivity in Bangladesh was studied by (Ruane et al., 2013), who highlighted that the beneficial effects of carbon dioxide on crop production vary with the emissions scenario. Decreased output occurs in impacted regions as the extent of river flooding increases. Additionally, (A. Rahman et al., 2009) overviewed the changes in behavior of temperature, precipitation, river overflows, and sea level rise and warned that not only the agriculture of Bangladesh, but also some regions of the country, might be submerged under water. Therefore, identifying adaptation strategies that address specific impact factors and vulnerabilities is urgently needed. Similar climate change impact for field crops in Bangladesh reviews have been provided by (Agrawala et al., 2003; A. U. Ahmed, 2006; M. S. Hossain, Qian, et al., 2019; Tanner et al., 2007).

Numerous studies have investigated agricultural risks globally, uncovering a multitude of factors. However, scant research exists on this topic, particularly in nations like Bangladesh. This research gap is striking and vital, as it hampers effective policymaking and interventions to bolster farming and enhance productivity. Addressing this gap is pivotal for sustainable agriculture. Thus, our study aims to analyze risk and uncertainty factors in Bangladeshi crop agriculture, linking them to recommend proper policies which can potentially enhance long-term food security and farmers' livelihoods.

3. Sampling, Data, and Methods

3.1 Study site selection and the rationale

We took great care in the selection process, concentrating our focus to the five most important agricultural districts in Bangladesh (Faridpur, Rajbari, Kushtia, Pabna, and Jhenaidah) to guarantee the highest quality of our findings. The main rationale behind this selection is that the first four districts were chosen because of their proximity to the Padma River, one of the most preeminent waterways in Bangladesh, which presents severe challenges for local farmers. We noticed that riverfront farmers often face greater levels of difficulties such as river erosion, floods, and soil fertility loss due to siltation (Dulal & Newaz, 2020; M. Hossain, 2020). It is also well-known that agricultural families in riverine areas tend to be fairly poor, which leads to a lack of resources for investment in agriculture, low inceptive for diversifying crops, reduced frequencies of cultivation, and a general lack of knowledge with modern agricultural practices. In addition, most farmers still utilize outdated methods of farming since they lack knowledge about the latest developments in agricultural technologies. Not only do they not have much experience with scientific farming methods, but they also rely significantly on natural irrigation such as rainfall and receive few resources from the government and other groups. Farmers get low prices for their goods and are highly exploited by intermediaries due to the regions' far away from consumer markets. Consequently, farmers in these areas tend to develop the perspective that farming is not as an end in and of itself but as a high-risk occupation and a nonprofitable business.

On the other hand, farmers in places like Jhenaidah may not have to deal with river erosion, but they still experience a number of other risks and uncertainties, including droughts, hailstorms ("Amphan: Jhenaidah Farmers Suffer Losses about Tk 900m," 2020), pest infestation and diseases, high input cost, etc. Based on the information provided, it can be inferred that the risk and uncertainty patterns in crop agriculture throughout Bangladesh are likely similar to those we focused on.

3.2 Sampling procedure

In order to obtain the most accurate results of our study, we sampled 400 farm households from Bangladesh. In this pursuit, we employed the multistage sampling technique with the utmost prudence. First, we purposively picked five agriculturally significant districts in both the northern and southern regions of Bangladesh: Faridpur, Rajbari, Kushtia, Pabna, and Jhenaidah. Of these, first four but not Jhenaidah are located nearby the Padma River. Next, we randomly selected two upazilas from each district and two union parishads from each upazila. Subsequently, we selected two villages at random from each union based on the intensity of farming practices. This resulted in the selection of 40 different villages. Lastly, we randomly select 400 farm households from among these 40 villages. These households are engaged in crop agriculture and would be the most representative for every region of Bangladesh, except hilly areas.

3.3 Data collection method and sources of data

Given the paramount significance of the input provided by field-level farmers to the outcome of this study, a comprehensive field survey was executed to secure information from farm households in the study area. A sample size of 400 farm households was deemed sufficient to draw statistically valid inferences about the population. To collect data, a semi-structured questionnaire was crafted to encompass a wide range of subjects including the farm households' demographics, socioeconomic features, risks, and uncertainties they face. The questionnaire underwent a rigorous pre-testing process to ensure its validity and reliability.

To ensure that all data collected was reliable, a team of data collectors was given a detailed briefing on the survey's methodology and training on the questionnaire. Selected farm households were given a questionnaire and were also interviewed by data collectors in order to compile the data. Lastly, face-to-face interviews were administered after the questionnaire was filled out to gather additional information and give respondents a chance to edit on their initial opinions. The questionnaires were double-checked for accuracy and completeness after data collection, and any discrepancies or missing information was rectified before being entered into a computer for analysis.

Our data collection strategy, comprising both field surveys and interviews, enabled us to acquire primary data that we then utilized in performing principal component. To enhance the comprehensiveness and depth of our study, we also drew upon secondary data gathering from sources like academic literature, pertinent websites, and agricultural organizations.

3.4 Method of identifying risk and uncertainty factors

To identify and then quantify the various risks and uncertainties perceived by farmers, we first gathered information through a structured manner that included reviewing relevant literature in agriculture, talking to agricultural experts and other stakeholders, holding focus groups with farmers, frequently visiting study areas, observing crop markets and farmers' attitudes, and conducting interviews with farmers. We then established a Likert scale rating system, with 1 indicating "not influential" and 5 denoting "extremely influential," to gather farmers' perceptions of each identified risk and uncertainty. Lastly, the Likert scale ratings were used to quantify the farmers' opinions on the perceived level of influence of each risk and uncertainty. The entire process was constructed by following (Panda et al., 2012a) and (Aditto et al., 2012).

3.5 Factor analysis: Principal Component Analysis

We differentiate the uncertainty from the risk as the uncertainty is the consequences of risks faced by the farmers. So, the same method of factor analysis is run for both the risk and the uncertainty.

In doing factor analysis, we first, conduct Cronbach's Alpha and intra-class correlation coefficient for the reliability test to evaluate the internal consistency of each factor over the collected data in order to verify whether the data set is suitable for factor analysis or not. Then, we use principal factor analysis with varimax rotation method to reduce the dimensionality of large data sets by transforming a large set of variables or components into a smaller one that still covers most of the information in the data set, i. e., extract the latent factors that reduce the whole factors into a smaller category. The PCA is the linear combinations of the factors, and the obtained factors are uncorrelated. This criterion is calculated as follows (Essa & Nieuwoudt, 2003):

$$PC_i = b_{i1}X_1 + b_{i2}X_2 + b_{i3}X_3 + \ldots + b_{ip}X_p$$

Where, PCi are the Principal components, known as Latent variables (LVs), X1, X2, X3, ..., Xp are the independent variables indicating the values we obtained by using five-point Likert scale based on the opinions of farmers on risks and uncertainties perceptions, and bi1, bi2, bi3, ..., bip are the coefficients measured so that the first latent variable demonstrates greater contribution than that of other LVs, and is uncorrelated with the second LV and so on (W. L. Nieuwoudt, 1972).

The data sets' suitability and appropriateness for factor analysis was evaluated using the Kaiser-Meyer-Oklin (KMO) index, which can take values between 0 and 1, with values of 0.6 or higher indicating suitability. Afterward, the latent root criterion (Eigen value > 1) was applied to each dataset to establish the optimal number of variables to extract. The orthogonal (varimax) rotational approach was used to reduce the number of variables with large loadings on each factor once the number of factors was determined. Factor loading ± 0.4 was employed as a threshold for determining the correlation between the initial variables.

3.6 Reliability and validity test of LVs

The latent variables we figured out using PCA were tested with Cronbach's alpha and composite reliability (CR) [CR = $(\sum \lambda)^2$/ [$(\sum \lambda)^2 + \sum(1-\lambda^2)$; λ = factor loading scores] indices for checking inter-variable reliability and factor model reliability respectively. If the value of both indices is greater than 0.7, the LVs are reliable (Golbasi et al., 2015; Masaeli et al., 2013). On the other hand, the factor analysis model, i.e., the PCA gets convergent validity (CV) when the average factor loading (AFL) is greater than 0.70, average variance extracted (AVE) [(AVE = $\sum \lambda^2/n$); n = number of factors constitutes a LV] exhibits higher value like 0.50, and CR>AVE (Golbasi et al., 2015; Masaeli et al., 2013). Finally, the PCA needs discriminant validity and if Maximum shared variance (MSV) calculated by using square of the highest correlation values of the factor loadings and Average shared of average of correlation values (ASV) measured with the aid of square of average of correlation values of the factor loadings are really lower than AVE. in this connection, Fornell-Lorcker Criterion used by (Azka, 2021), announces that if Square root of AVEs is higher than all respective correlation values (along vertical), no validity concerns.

4. Results and Discussion

The entire dataset was analysed with SPSS version 26 software and in some cases, the Microsoft office excel program. The analysis is mainly divided into two sections- (1) risk factor analysis and (2) uncertainty factor analysis. These two sections are again separated into three main parts such as farmers' perception regarding risk and uncertainties, risk and uncertainty differentials over the study areas, and finally the factor analysis.

4.1 Identifying factors explaining risks: Principal Component Analysis

Discussion of the results of the factor analysis for risk and uncertainty factors are presented here. The information was analyzed using SPSS version 26 and principal component analysis with direct oblimin rotation method was applied for factor analysis. A number of risks and uncertainties factors are narrowed down for various groups of farmers by means of principal component analysis.

4.1.1 Reliability test for factor analysis: Cronbach's alpha

Table 03 (a): Reliability test for entire risk factors: The Cronbach's alpha		
Reliability Statistics		
Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
0.785	0.794	55
Table 03 (b): Reliability test with intraclass correlation coefficient		
Intraclass Correlation Coefficient (ICC)		

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	0.039[a]	0.031	0.049	4.654	399	21546	0.000
Average Measures	0.691	0.639	0.738	4.654	399	21546	0.000
Two-way random effects model where both people effects and measures effects are random.							
a. The estimator is the same, whether the interaction effect is present or not.							
b. Type A intraclass correlation coefficients using an absolute agreement definition.							

Table 03 (a) shows the results of a reliability test using Cronbach's alpha for an entire set of 55 risk factor items. The Cronbach's alpha coefficient was found to be 0.785, indicating good internal consistency. The Cronbach's alpha based on standardized items was 0.794.
Table 03 (b) shows the results of the reliability test using the intraclass correlation coefficient (ICC). The single measures ICC value is 0.039 with a 95% confidence interval of 0.031 to 0.049, which is low. The average measures ICC value is 0.691 with a 95% confidence interval of 0.639 to 0.738, indicating acceptable reliability. The F test with true value 0 shows a significant result, with a p-value of 0.000. The two-way random effects model with both people and measures effects as random is used, and the type A intraclass correlation coefficients are calculated using an absolute agreement definition.

4.1.2 KMO and Bartlett's test
Table (05) shows the results of a factor analysis of risk variables. The Kaiser-Meyer-Olkin measure of sampling adequacy is 0.841, which indicates that the sample size is adequate for the analysis. Bartlett's test of sphericity yielded an approximate chi-square value of 11467.962 with 1485 degrees of freedom and a significance level of 0.000, indicating that the correlation matrix of the risk variables is not an identity matrix and is suitable for factor analysis.

Table 05: KMO and Bartlett's Test for factor analysis of the risk variables.		
Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy		0.841
Bartlett's Test of Sphericity	Approx. Chi-Square	11467.962
	df	1485
	Sig.	0.000

4.1.3 Results and discussion of the risk factors analysis

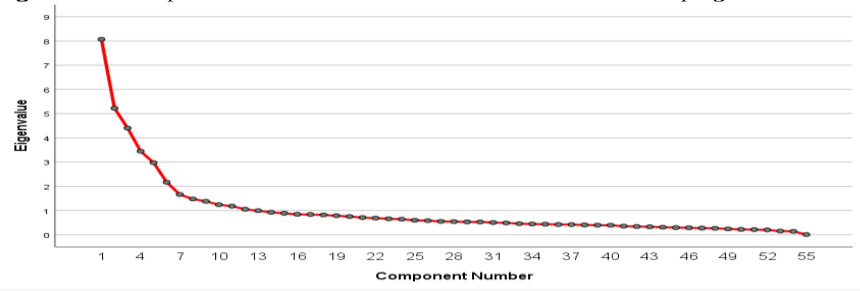
Summarizing the outcomes of a PCA with varimax orthogonal rotation on crop agriculture risk factors, the table (06) lists the factors considered and their respective loadings on 12 latent variables. Communalities display the fraction of variance in each factor explained by the latent variables. Extraction communalities range from 0.439 to 0.940, indicating that not all variance is accounted for by the extracted factors. The table reveals 12 latent variables from 55 risk factors by using the criterion of eigenvalues > 1 (also see fig. 03: scree plot), with the first LV accounts for 14.67% of the total variance, the second 9.494%, the 3rd 8.004%, the 4th 6.266%, the 5th 5.404%, the 6th 3.935%, the 7th 3.018%, the 8th 2.681%, the 9th 2.502%, the 10th 2.248%, the 11th 2.144% and the last one 1.907%. Collectively, the LVs explain 62.274% of the total variance, and most have Cronbach's Alpha greater than 0.6, indicating sufficient reliability. However, some factors such as PCR12 and PCR8 have low alpha, and "poor fertile land" should be excluded due to low cut-off and communalities. Deleting the factor "lack of market information" from PCR8 increases its alpha to 0.62, indicating higher reliability.

Table 06: Principal Component Analysis for the risk factors												
	Factors explaining crops' risks (LVs) and their loadings (λ)											Communa-lities
Risk factors	PCR1	PCR2	PCR3	PCR4	PCR5	PCR6	PCR7	PCR8	PCR9	PCR 10	PCR 11	PCR 12	extraction
Fertilizer shortage on time	.883	.140	-.140	.042	.017	.004	.065	.028	-.068	.016	-.055	-.041	0.84
Vulnerable power system	.859	.134	-.075	.006	-.031	-.059	.062	-.020	-.002	-.034	-.069	-.023	0.78
Irrigation equipment problem	.854	.106	-.072	.040	.010	-.026	.041	.081	.101	-.032	-.043	.027	0.77
Insufficient crops' seeds	.845	.098	.000	.008	-.063	-.060	.030	.081	.043	.004	.076	-.013	0.75
Lack of advanced varieties	.762	.040	-.030	-.019	.006	-.064	-.005	-.030	.141	.029	.095	-.047	0.62
Water supply problem for irrigation	.737	.096	.164	.051	.024	-.017	.036	.010	-.021	-.021	-.128	.051	0.60
Effective pesticides unavailability	.730	.150	.053	.145	-.064	.108	-.072	.066	-.020	.065	-.058	-.041	0.61
Labor shortage in transplanting and harvesting time	-.513	-.001	.147	-.014	.052	-.003	-.137	.401	.075	-.096	.124	-.122	0.51
Inferior variety of seeds	.473	.419	-.220	-.045	.052	.016	.152	-.086	-.161	.143	.121	-.076	0.55
High distance of underground water	-.440	-.055	.160	.013	.126	-.063	-.038	.389	.005	-.211	.166	.017	0.47
Lack of production skill	.175	.793	-.097	.009	.067	.028	-.034	.002	-.027	-.034	.021	.015	0.68
Excessive production cost	.005	.788	-.039	-.079	.022	.004	.006	.068	.068	-.095	-.096	-.059	0.66
Crops waste after harvesting	-.146	.756	.050	.070	-.013	-.016	-.034	.069	-.059	.043	-.102	.021	0.62
Over utilization of land	.159	.749	.017	.018	.021	-.110	.040	.008	-.007	-.046	-.046	.068	0.61

Low output	.088	.742	-.005	-.002	.017	-.082	.049	.001	-.137	.043	.071	.068	0.60
Damage by pest infestation and diseases	.101	.736	-.042	.008	.057	-.005	-.009	-.013	-.064	.049	.047	.075	0.57
Soil fertility damage by siltation	.035	.724	.007	.037	-.016	.120	-.006	-.080	.003	.089	.074	.046	0.56
Lack of production coordination among farmers	.181	.679	-.051	-.055	-.032	.113	-.145	-.016	.053	.021	.106	.076	0.55
Paucity of skill development/ training facilities	.083	.672	-.060	-.014	.036	.001	-.040	-.050	.043	-.075	-.146	-.198	0.54
Stochastic behaviour of yields	.314	.579	-.142	-.120	.097	-.043	.058	.034	.080	-.096	-.125	-.084	0.52
Damage by hailstorm and storm	.022	-.024	.854	.027	.012	.019	-.034	.023	-.048	.034	.003	-.026	0.74
Severe drought/ Delayed rainfall	-.028	-.056	.822	-.061	.030	.046	.015	.048	.110	-.021	-.080	-.079	0.72
Flood/ Heavy rainfall	-.093	-.079	.807	.043	-.100	.060	.009	.015	-.060	-.014	.085	.011	0.69
River erosion/ land slides	-.134	-.095	.796	.105	.005	.008	-.062	.023	-.106	.045	.018	.037	0.69
Community/ family discord	.026	.056	-.009	.804	-.043	.014	.191	.120	.090	-.018	.034	.044	0.72
Vulnerable product management and packaging system	.059	-.070	.101	.779	-.013	-.022	.047	.031	.168	.019	.115	.023	0.67
Crops perishability	-.007	-.040	.050	.774	-.051	.029	.117	.139	.165	-.027	.062	-.006	0.67
Livestock injury and death	.100	-.005	-.015	.744	.064	-.028	.105	.024	.219	.020	.021	-.028	0.63
Arable land scarcity	-.063	.004	.022	.011	.843	.079	-.009	-.038	.007	-.087	.020	.006	0.73
Landlessness	-.079	.105	-.034	.000	.786	.199	-.015	.063	-.052	.001	.004	.148	0.70
Land fragmentation	.040	.109	-.053	-.035	.776	.092	.026	.115	.005	-.004	.141	.018	0.66
High interest rate	-.032	.018	.064	.000	.177	.943	-.010	.004	-.007	.017	.093	.067	0.94
Inadequate credit facilities	-.028	.023	.065	-.001	.184	.943	-.012	.006	-.001	.013	.092	.054	0.94
Financial vulnerability	.028	-.019	.015	.012	.229	.465	.131	.102	-.002	-.095	-.216	.423	0.53
Poor fertile land	-.097	-.081	.029	-.043	.357	.360	.079	.142	-.062	-.207	-.234	.189	0.44
Lack of medical care	.055	.025	-.094	.115	-.068	.037	.793	.040	.057	.034	.103	.088	0.69
Capital inadequacy	.126	-.002	.034	.140	.041	-.005	.784	.048	.080	.017	.046	.021	0.66
Unnecessary spending due to corruption	.262	-.087	-.098	.221	.099	-.034	.555	-.149	.256	.046	.192	-.113	0.59
Lack of literacy knowledge	-.340	-.155	.077	.182	.024	.038	.490	-.032	.216	-.035	.191	-.100	0.52
Low output price	.092	-.039	.078	.105	.021	.017	.043	.696	.136	.085	-.069	-.089	0.55
Exploitation by middlemen	-.067	.010	.123	.202	.072	.115	-.034	.655	.190	.163	-.174	-.034	0.60
Hazard pricing system	.314	.072	-.114	.071	-.022	-.048	.039	.507	.138	.008	.043	.272	0.48
Lack of market information	-.254	-.048	-.068	-.050	.043	-.001	-.057	.478	-.174	-.147	.354	.239	0.54
Inadequate market-based infrastructures	.423	.083	-.252	.252	.081	.068	.091	.438	-.079	-.061	-.081	-.234	0.60
Increased fuel cost	.009	-.008	.003	.135	.000	-.041	.148	.063	.651	.105	.109	.231	0.55
Vulnerable storage capability	.085	.010	-.067	.316	-.031	-.032	.192	.149	.620	.015	-.005	.058	0.56
Equipment damage	.113	-.107	-.088	.240	.125	-.018	.041	.108	.574	-.036	.021	-.277	0.53
High procurement cost	-.074	.001	-.023	.167	-.152	.054	.040	.068	.509	-.103	.205	.018	0.38
Social, fiscal, animal, construction, environmental and tax policies	.027	-.057	.004	.005	.074	.016	.008	.036	.044	.851	.037	-.063	0.74
Adverse agriculture policy	.063	.025	.042	-.018	-.167	-.052	.047	.055	-.063	.812	-.063	.053	0.71
Limited facilities from Government	-.180	-.086	.028	.054	.056	.025	.152	-.012	.158	.023	.654	.023	0.52
Political instability	.057	.045	-.030	.211	.021	.087	.329	-.096	.156	-.030	.579	-.063	0.54
Variability in the world political environment	-.400	-.064	.148	.184	.059	-.012	.103	.029	.359	-.053	.417	-.024	0.54
Global Catastrophes like Covid-19	-.041	.040	-.048	.025	.112	.096	-.028	-.005	.076	-.031	.071	.703	0.54
Lack of weeds management technique	.016	.036	-.002	.001	.455	.199	.034	-.083	-.011	.104	-.196	.474	0.53
Eigenvalues	8.068	5.222	4.402	3.446	2.972	2.164	1.660	1.475	1.376	1.236	1.179	1.049	
Percent of total variance explained	14.670	9.494	8.004	6.266	5.404	3.935	3.018	2.681	2.502	2.248	2.144	1.907	
Cumulative percent of the variance explained	14.670	24.164	32.168	38.434	43.839	47.774	50.792	53.473	55.975	58.223	60.367	62.274	
Cronbach's Alpha	0.76	0.90	0.85	0.83	0.80	0.81	0.70	0.62*	0.60	0.68	0.60	0.40	
Number of variables	10	10	4	4	3	3	4	4	4	2	3	2	
Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization. Rotation converged in 8 iterations. 0.54 (5)													

The LVs' factors PCR1-11 can be labeled according to their significant loading variables. The significant loadings of Factor PCR1 on risk variables related to farmers' input issues led to its naming as "input risk." It is evident that PCR2 poses a "production risk" because of its link to production processes. PCR3 is called "climate change risk" as all risk factors are climate-related and negatively impact crop production. When it comes to identifying risk factors, PCR4 is known as "personal risk" because it focuses on farmers' personal and family issues. PCR5 is commonly referred to as "farm risk" for its focus on land-related difficulties. The financial insecurity of farmers and bureaucratic complications in obtaining loans makes PCR6 a "financial risk." PCR7 is designated as "socio-economic risk" for its association with farmers' socioeconomic standing. Market risk is PCR8 because it draws attention to the instability of market prices and the deficiency of a robust market infrastructure. There is "investment risk" associated with PCR9 since farmers have limited financial resources to invest on crop production and protection. PCR10 is known as "policy risk" because it emphasizes the potential for adverse impacts on farmers as a result of agricultural policies. Finally, PCR11 is classified as "political risk" due to the agriculture's reliance on national and international politics and government support.

Figure 3. Scree plot of the entire risk factors associated with crop agriculture.



4.2 Principal component analysis for uncertainty

Table 10 provides an overview of the findings from three distinct analyses conducted on the uncertainty factors faced by farm households. Specifically, Table 10(a) displays the results of a reliability test which yielded a Cronbach's Alpha value of 0.705, indicating a moderate level of internal consistency among the 10 variables included in the test. Moving on to Table 10(b), it can be observed that the KMO measure of sampling adequacy is 0.660, which is deemed to be fair, while Bartlett's test of sphericity is significant, indicating that the correlations between the variables are large enough to conduct a principal component analysis.

Table 10(c) reveals that four latent variables, or PCUs, were extracted through the principal component analysis with varimax rotation method obtained by 7 iterations. The four components accounted for 67.17% of the total variance, with eigenvalues greater than 1 (see also fig. 4). The communalities range from 0.328 to 0.875, implying that each uncertainty is significantly related to at least one latent variable. The Cronbach's alpha values for each latent variable range from 0.680 to 0.771, indicating a moderate to high level of internal consistency.

Table 10 (a): Reliability test for the uncertainty factors faced by farm households

Reliability statistics	
Cronbach's Alpha	No. of variables
0.705	10

Table 10 (b): KMO and Bartlett's test for uncertainty factors faced by farm households

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.660
Bartlett's Test of Sphericity	Approx. Chi-Square	914.199
	df	45
	Sig.	0.000

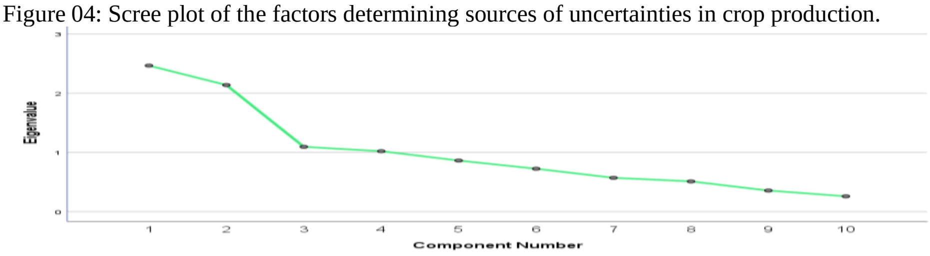
Table 10 (c): Result of principal component analysis for the uncertainty factors faced by farm households

Uncertainties in crop production	Latent Variables (LVs)				Communalities
	PCU1	PCU2	PCU3	PCU4	Extraction
Employment uncertainty	0.882	0.047	0.073	-0.001	0.785
Technological uncertainty	0.855	0.012	0.084	-0.094	0.747
Personal uncertainty	0.641	-0.021	-0.198	0.072	0.456
People's uncertainty	0.429	-0.159	0.003	-0.344	0.328
Output price uncertainty	-0.057	0.821	0.043	0.099	0.688
Uncertainty regarding input quality/ prices	0.069	0.739	0.152	0.078	0.580
Credit uncertainty	-0.073	0.728	0.259	-0.213	0.647
Tenurial uncertainty	-0.041	0.113	0.894	0.036	0.814
Output uncertainty	0.015	0.273	0.848	-0.032	0.796
Agricultural policy & global preference uncertainty	-0.016	-0.033	0.010	0.935	0.875
Eigenvalues	2.465	2.137	1.094487	1.020	
Percent of total variance explained	24.650	21.371	10.944869	10.203	
Cumulative percent of the variance explained	24.650	46.022	56.967	67.170	
Cronbach's Alpha	0.695	0.680	0.771	N/A	
Number of variables	4	3	2	1	

Extraction Method: Principal Component Analysis. Rotation Method: varimax with Kaiser Normalization. Rotation converged in 7 iterations.

The first LV, or PCU1, was named input uncertainty, as it is primarily influenced by employment uncertainty (0.882), technological uncertainty (0.855), personal uncertainty (0.641), and people's uncertainty (0.429), all of which are related to inputs of the farm households. The second LV, or PCU2, was assigned credit and price uncertainty as its name since it was mainly influenced by output price uncertainty (0.821), uncertainty regarding input quality/prices (0.739), and credit uncertainty (0.728). The third LV, or PCU3, represents yield uncertainty, being primarily influenced by tenurial uncertainty (0.894) and output uncertainty (0.848). Finally, the fourth LV, or PCU4, which is not reliable, was influenced mainly by agricultural policy and global preference uncertainty (0.935).

Figure 04: Scree plot of the factors determining sources of uncertainties in crop production.



5. Viability test of factor analysis

With regards to risk, the values of composite reliability (CR) of latent variables PCR1, PCR2, PCR3, PCR4, PCR5, PCR6, PCR7, and PCR10 are > 0.70, while for PCR8, PCR9, PCR11, and PCR12 it is < 0.70. Overall, the factor analysis has passed the composite reliability test. The factor analysis has satisfied the convergent validity test's conditions with |AFL| > 0.70, CR > 0.70, AVE > 0.50, and CR > AVE, indicating no convergent validity concerns. For the discriminant validity test, AVE > MSV and AVE > ASV, (all MSV and ASV are zero as the method is varimax rotation) and the Fornell-Larcker Criterion is achieved (Square root of AVEs > all respective correlation values), with no discriminant validity concerns.

Table 11: Composite reliability, convergent validity, and discriminant validity tests of the factor analysis for risk and uncertainty variables

Validity test for risk factor analysis					Validity test for uncertainty factor analysis				
LV	CR	AVE	SQRT (AVE)	|AFL|	LV	CR	AVE	SQRT (AVE)	|AFL|
PCR1	0.851	0.530	0.728	0.519	PCU1	0.789	0.526	0.725	0.701
PCR2	0.916	0.525	0.724	0.722	PCU2	0.749	0.584	0.764	0.762
PCR3	0.891	0.673	0.820	0.819	PCU3	0.667	0.759	0.871	0.871
PCR4	0.858	0.602	0.776	0.775	PCU4	0.500	0.874	0.935	0.935
PCR5	0.844	0.644	0.802	0.802					
PCR6	0.846	0.665	0.815	0.784					
PCR7	0.757	0.448	0.669	0.656					
PCR8	0.693	0.318	0.564	0.555					
PCR9	0.680	0.349	0.591	0.589					
PCR10	0.818	0.692	0.832	0.832					
PCR11	0.569	0.312	0.559	0.550					
PCR12	0.520	0.359	0.599	0.589					

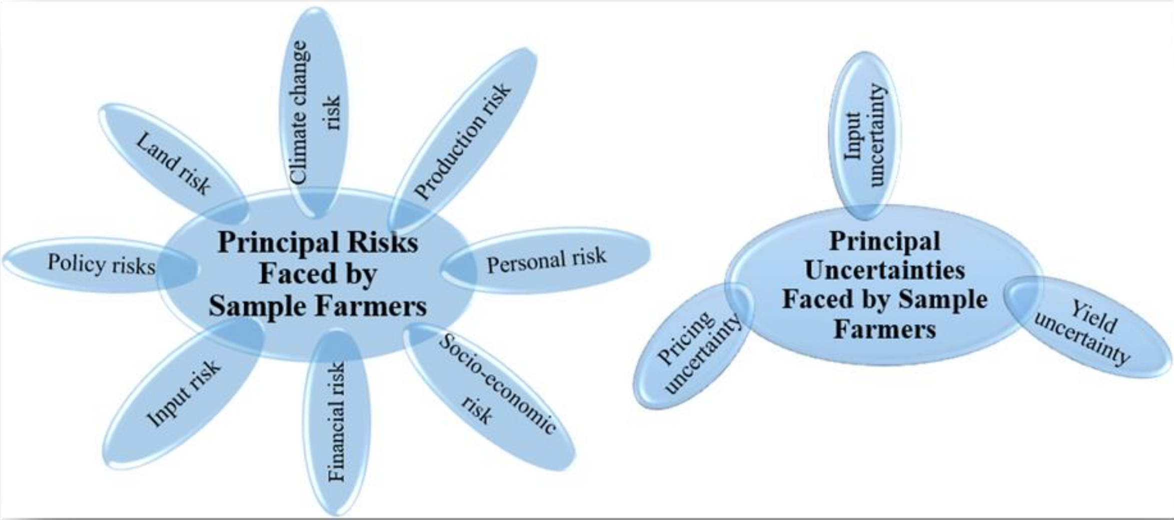
Regarding uncertainty, the factor analysis has successfully passed the composite reliability test with CR > 0.70. The factor analysis has also met the conditions for convergent validity with |AFL| > 0.70, CR > 0.70, AVE > 0.50, and CR > AVE, indicating no concerns in terms of convergent validity. In the discriminant validity test, AVE > MSV and AVE > ASV, and the squared value of AVE is greater than the correlation coefficient values both vertically and horizontally, thus satisfying the Fornell-Larcker Criterion. Therefore, no discriminant validity concerns were found.

6. Major Factors of Risks and Uncertainties

Principal component analysis (PCA) indicated that among the fifty-five factors affecting crop production in the study area, twelve principal factors could adequately describe these outcomes. Similarly, when examining the uncertainties in the districts, four main factors are identified as responsible for the ten uncertainties. Nevertheless, it should be noted that the tests of reliability and validity yielded interesting insights. In particular, four major risks—i.e., market, financial, political, and other risks—with an item related to agricultural policy and global priority uncertainties were found to lack significant assessment reliability and validity in the particular circumstances.

As a result, eight major risk factors and three major uncertainties emerged as statistically robust factors (as depicted in Figure 5). These factors are important in terms of adverse effects on crops grown in the study areas. Finally, we gain a clearer understanding of the factors affecting actual crop cultivation in the study area through the rigorous scrutiny of these factors.

Figure 5. Demonstration the Reliable and Viable Latent Factors of Risks and Uncertainties



7. Conclusion and Recommendations

Agricultural risk to crops varies from region to region due to factors such as climate, geography, economy, socio-economic status of farmers and government policies. North Bangladesh faces frequent natural disasters, while the south suffers from water scarcity. Access to resources such as irrigation, seed and credit also affects risk. Better areas offer better access. Using PCA, we classified 55 risk factors into 12 groups, but one lacks validity. Key risks include production, prices, inputs, investment, climate change, socioeconomic, policy, and political risks. PCA identified four uncertainties from 10 categories, but only three met validities: input (IU), yield (YU), and pricing (PU) uncertainty.

These risks and uncertainties have dire consequences for agriculture, farmer income and the economy. Immediate protection is required. Solutions proposed include crop diversification, insurance, income diversification, market linkages, access to credit, technology adoption, climate-smart practices, government support, local crop selection, irrigation, soil conservation, weather forecasting, extension services and research support to improve regional agriculture and make resilience and longevity for the crop economy in Bangladesh.

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