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# Relationships Between Food Systems, Agricultural Practices, and Food Security Amidst Climate Change in Western Bhutan

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## ABSTRACT

An estimated 80% of the global population, mostly poor and vulnerable farmers, are at risk of crop failure and hunger due to climate change. Food systems are the networks for organizing food production and distribution that make meals possible at the level of the consumer, however, the networks are varied. Agricultural practices are farming methods that are used to facilitate agriculture. An economic and social condition of ready access by all household members to nutritionally adequate and safe food will ensure food security. The intricate and interconnected relationship between food systems, food security, and agricultural practices amid climate change involves significant impacts on productivity, crop yields, and food resource availability, necessitating resilient and adaptable food systems to address challenges posed by climate-induced variations and ensuring overall sustainability. The study aims to assess the relationships between agricultural practices and food systems and their implication for food security in the changing climate in the three climatic zones of Gasa, Wangdue, and Punakha. Agricultural practices in Gasa, Punakha, and Wangdue districts (Dzongkhag) were compared and relationships were drawn. The sample for the study was 360 households stratified into three climatic zones (120 households in each zone), in five sub-districts (Gewog) having 12 villages (Chiwog) taking 30 randomly selected households from every village. Household-level data was collected using the survey method by administering the pretested semi-structured questionnaire. Agriculture productivity data and climate data for the last 23 years were gathered from the National Statistical Bureau (NSB) and the National Centre for Hydrology and Meteorology (NCHM) respectively. Food systems are fragile and present agricultural practices significantly impact food security. A systematic land leasing programme (SLLP), climate-smart agriculture mass land management for mechanized farming are recommendations from this study.

## INTRODUCTION

### Background

Food production, processing, distribution, and consumption are all part of complex networks of activities, procedures, institutions, and players collectively known as food systems (Ericksen *et al.*, 2009). They cover the full food supply chain, from the beginnings of food production on farms and in fisheries to its final consumption by people and groups in society. Everything from crop planting and harvesting, livestock husbandry, fishing, food processing, retailing, and preparation to waste management and disposal is included under food systems. Global environmental changes such as land degradation, loss of biodiversity, changes in hydrology, and changes in climate patterns due to amplified anthropogenic emission of greenhouse gases, will have serious consequences on food systems, especially for more vulnerable groups (Ericksen *et al.*, 2009).

Food security refers to the state in which all individuals have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life. In simple terms food security is referred to as regularly having enough food to eat; not just for today or tomorrow, but also for next month and next year (Gibson, 2012). Another way is to measure food insecurity to assess food security status as proposed by (Cafiero *et al.*, 2018) where authors defined the eight-item Food Insecurity Experience Scale (FIES) as a contribution to establishing an indicator for global monitoring of food insecurity. It is a critical aspect of human well-being and an essential component of sustainable development. Four important dimensions make up the idea of food security. Firstly, availability on the national and international level, there must be reliable production of sufficient amounts of food. Agrarian systems that ensure that everyone has access to food include production, distribution, and market structures. Accessibility is when people can acquire food, either through independent food production, market purchases, or government interventions like food assistance programs. Elements like food costs, income levels, and transportation may impact the accessibility of a site. Thirdly, utilization of food must be wholesome, culturally suitable, and safe to meet one's nutritional requirements. Finally, stability is maintaining consistency across time and in a variety of situations which is necessary for food security (USAID, 2008). Four factors threatening the state's food security were identified as it is essential to recognize and address food security challenges that it is an important component of national security (Umarjonovna & Gulomjonovna, 2022).

Climate change is the key variable that can affect food

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security where crop yields and food production may be affected, which could result in a food crisis. As a result of climate change, crop yields and food production may be affected, which could result in a food crisis. Several issues that endanger global food production and distribution are brought on by climate change, which has a significant impact on food systems, food security, and agricultural practices. A complicated and critical global concern is addressing how climate change is affecting agricultural practices, food security, and food systems. Building resilient and sustainable food systems that can resist the challenges posed by climate change while providing food security for all depends on combining the efforts of governments, farmers, corporations, and civil society. A complex relationship exists between agricultural methods, food systems, and food security. For promoting food security, ensuring a reliable and diverse food supply, and minimizing the detrimental effects of food production on the environment, sustainable and resilient agricultural practices are crucial. However, a study on resilience and the industrial food systems by Umarjonovna & Gulomjonovna, (2022) postulated that food system is becoming less resilient to external shocks such as climate change and suggested four possible strategies to restore resilience especially programs to promote food system localization.

This study aims to analyse agricultural practices and food systems in changing climates and their effects on food security in different ecological zones. It will include data sources from the National Statistical Bureau (NSB), National Centre for Hydrology and Meteorology (NCHM) and survey data from the study area for a systematic approach to address the objective. The study sites have three agroecological zones based on altitude as alpine zone, the cool temperate zone, and the dry sub-tropical zone. The altitudes of the alpine zone are above 3600 meters above sea level (masl), the cool temperate zone between 2600 to 3600 masl and the dry sub-tropical zone falls within 1200 to 1800 masl.

Climate change trend is the overarching phenomenon to assess the current situation and predict the future food security status. The demographic status determines the land holdings for food production, remittance for food purchase, labour for food production and dependency on food production and consumption. While basic nutritional requirement in terms of calorific needs for all human beings is the same, different agroecological zones will be producing different kinds of food and are accessible (through the import of food) to different kinds of food thereby varying nutritional security. A study by Adeoye (2023) indicated that improper post-harvest handling of food in the food value chain is a challenge to food and nutrition security. This is mor relevant to smallholder farmers like ours. Food production in different agroecological zones is different due to different climatic conditions and altitudes impacting different food flows, unique food supply chains and food value chains. All these interactions generated a particular type of food system that enabled to forecasting of food security or food insecurity status in the regions. Food security domains such as availability, accessibility, utilization and stability are the basis of assessing the food security status of the regions.

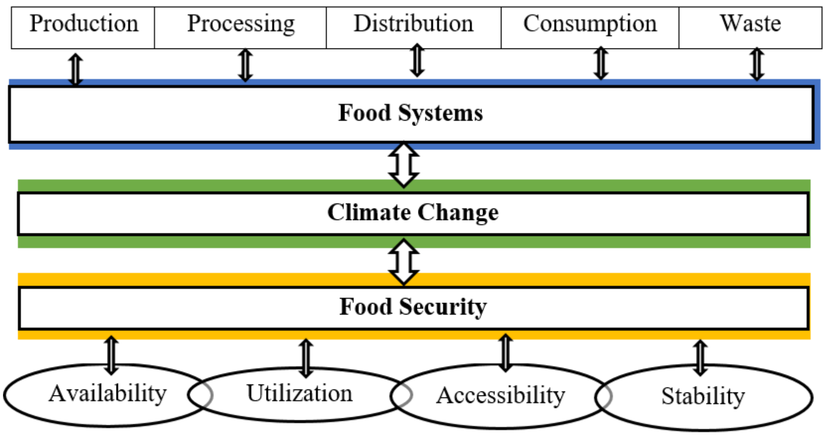


**Figure 1:** Conceptual flow of food factors that create interlinked relationships with Climate Change

A framework proposed by Béné *et al.*, (2023) uses to assess food system resilience at the local level. The same study then proposes assessing food systems combined efforts to enhance or disrupt food security and nutrition status at local level. This study adopts similar scale (the three agroecological zones) because focusing on the local level allows us to understand the food system at a level of specificity needed to diagnose and remedy the functional integrity of food systems (Béné *et al.*, 2023). The study employed both primary and secondary data sources, focusing on three distinct agroecological zones. Primary data was collected on the production, sale, and consumption of selected food groups, while secondary data included climate information for these regions, specifically temperature and precipitation data during the growing seasons. Agricultural practices play a crucial role in enhancing agricultural productivity, comprising a set of farming techniques designed to improve crop yields. A simple agricultural practice proposed in design and development of an engine driven onion grading machine is found to be suitable for small and medium-scale farmers (Tafa, W., & Olaniyan, A. M., 2023). livelihood These practices encompass strategies like crop rotation, mixed cropping, relay cropping, two-cropping agriculture, multi-cropping agriculture, and the integration of crops and livestock within farming systems, among others.

The findings are presented in the form of a clear and organized manner, using tables, graphs, and charts to visualize the data with concise narrative descriptions and discussions appropriately to explain the findings. Further engagement in discussions on the implications of findings and potential policy interventions to enhance food security in these ecological zones are the study's conclusions. This study can be the basis for thoroughly analysing the impact of agricultural practices and food systems on food security in different ecological zones, providing a basis for informed decision-making and policy development.

## METHODOLOGY

### Research Design

Agricultural data from the National Statistical Bureau (NSB) were obtained on agricultural production in each ecological zone. This included information on the production of cereals (wheat, rice, maize), vegetables (potato, spinach, radish, beans), meat products (yaksha/beef, chicken, pork, eggs), and dairy products (milk, cheese, yoghurt, butter). Accordingly, data on crop yields, livestock production, and dairy output were also gathered from the survey. Climate data on temperature and precipitation for each ecological zone, specifically for the sowing and harvesting seasons of the crops, were obtained from the National Centre for Hydrology and Meteorology (NCHM). This helped in understanding the climate conditions in these zones and could triangulate with the climate perception data from the survey from the fields. Food composition data were gathered from surveys to collect data on what people in these zones have eaten in their meals over the past 24 hours, what all major foods are produced, the processing of food, food distribution or food flow, and food waste. This provided insights into the composition of their diets, acquisition of food and food waste generated after consumption. The analysis included an assessment of self-production versus imported food compositions. This analysis determined as to what proportion of the food consumed in each ecological zone is produced locally and what is imported. The information was obtained from trade data and local production statistics. Further, net food surplus or shortage calculations of the total food production (cereals, vegetables, meat products, and dairy products) in each ecological zone to the total food consumption is determined to identify whether there is a surplus or shortage of food in each zone. Food Security status was finally evaluated in each ecological zone based on the data collected considering the factors such as food availability, accessibility, utilization, and stability. Literature on the nutritional content of diets, income levels, and other relevant indicators were referred to have the basis to determine the food security status. Based on the analysis, conclusions were drawn for each food category (cereals, vegetables, meat products, and dairy products) in each ecological zone. Assessment of surplus or shortage of each food type and how it impacts food security is derived. Issues with food security in any of the zones are provided with appropriate recommendations for improving the situation including changes in agricultural practices, climate adaptation strategies and trade policies. The relationship of climate change to food systems and food security provides synergy in the following framework.

The food security assessment and food system resilience approaches were adopted using the four domains of food security and food systems assessment framework following research methods adopted in earlier studies (Béné *et al.*, 2023; Cafiero *et al.*, 2018; Conforti, 2003; HLPE, 2017). Firstly, through the approach of comparison and building relationships, the study adopted a cross-sectional research design. Cross-sectional research design in the three climatic zones enabled to collection of data from a single point in time from a wide range of respondents with a wide range of variables considered. Secondly, a longitudinal design was adopted to gather the time series data. climate data (temperature and rainfall) for three decades were gathered from the National Centre for Hydrology and Meteorology (NCHM). Similarly, agricultural production data from the National Statistical Bureau (NSB) in primary food commodities (five cereals, five vegetables, dairy products and meat products) were identified and collected. To establish relationships and for comparison through analysis of association as stated by Kesmodel (2018), climate change, food security and food production practices in different agroecological zones were analysed. The quantitative approach of collecting data using a semi-structured questionnaire was adopted. Data was collected from surveying any one member of the household farmers using a semi-structured questionnaire to ensure randomness as well as inclusiveness of the respondents from within the household of the study site. The study provided a snapshot of the present food systems and status and food security in the three districts of Gasa, Wangdue Phodrang and Punakha during 2022 and 2023.

### Study Area

The study site has been divided into three agroecological zones (Rai *et al.*, 2020). Gasa falls into the Alpine zone with above 3600 meters above sea level. Wangdue Phodrang is under a cool-temperate zone at 2600 to 3600 meters. The lowest agroecological zone (Punakha) is the dry sub-tropical zone within 1200 to 1800 meters. For assessing variation of agricultural practices that determine food systems and food security status of the regions in question, the zoning provided a convenient way to compare them with each other. As shown in

Figure 2, the study collected data from three zones of alpine, cool temperate and dry sub-tropical zones from three districts of Gasa, Wangdue Phodrang and Punakha respectively. Gasa had one Sub District Laya with four villages namely Chongro, Lungo, Nelu and Pazi. Wangdue Phodrang District had two sub-districts namely Gangtey with Gogona and Kumbu villages and Phobji with Gangphel and Drangha. Similarly, Punakha District had two sub-districts namely Kabisa with Angona-Zabisa and Petari villages and Dzomi with Gubji-Tsekha and Tana-Uesa villages. The study map is shown in Figure 2.

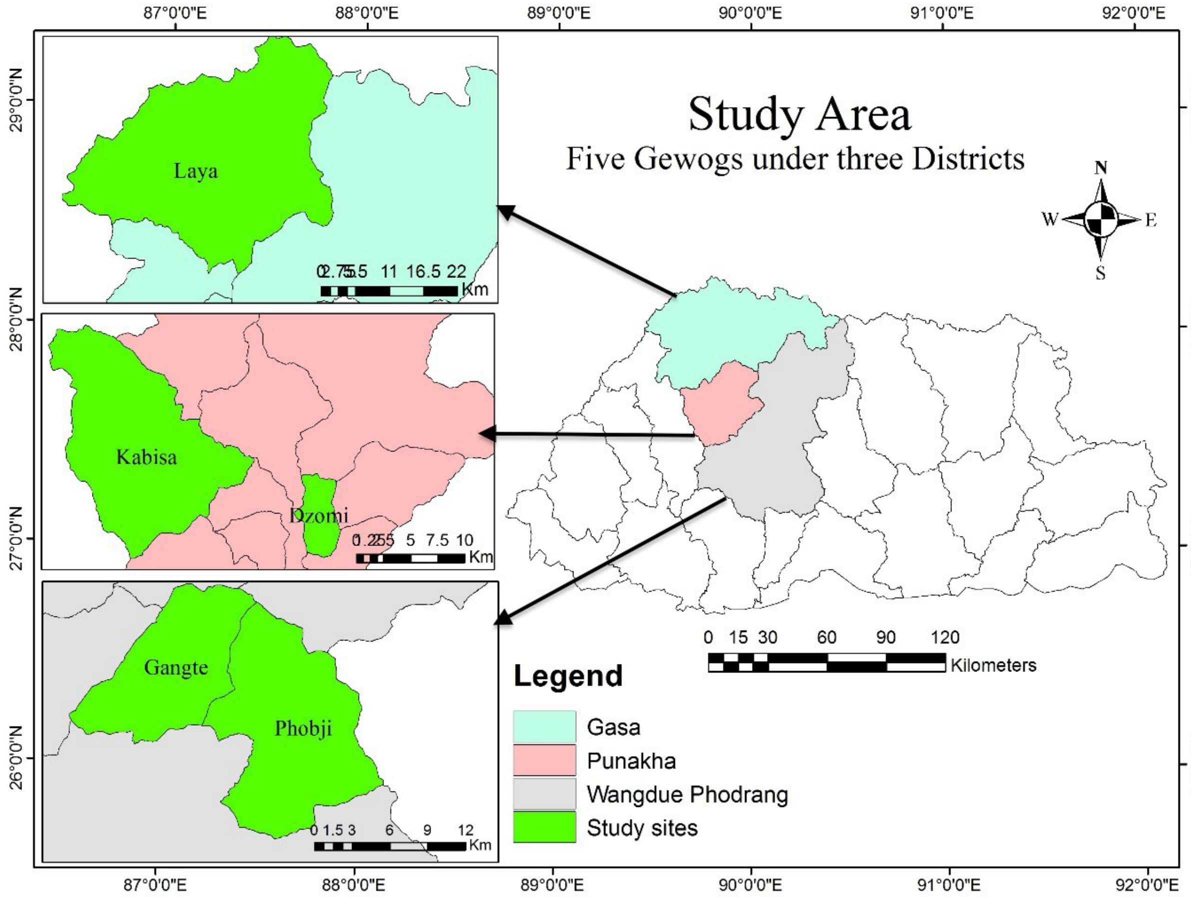


**Figure 2:** Study area, three ecological zones

The three zones are different in terms of rural or urban settings: Laya in Gasa is far away in a remote setting with a walk distance of 30 km from the end of the vehicle road. Wangdue Phodrang District having Gangtay and Phobji sub-districts are away from the national highway connected with narrow and unstable farm roads as semi-rural communities. Punakha district with Dzomi and Kabisa sub-districts are next to the national highway with an urban town within 5 km from the communities.

**Sample Size**

The target population was instrumental in having a scope and coverage of the study. The unit of sample is a household – any respondent (above 15 years) can be a member of the household as the household was the unit of parameter and statistics. A respondent had to be a member of the household, from the farming community, staying in the village, and a practising farmer. The initial list of 1822 households was provided by the five Gups (the heads of the local government). However, some households without members staying in the village had to be excluded. After subtracting 21 households without members doing farming, the final list had 1801 households in the population was confirmed.

To determine the minimum sample size, Cochran's formula was used (Cochran, 1997). For the desired level of precision, desired confidence level, and estimated proportion of attributes present in the population, Cochran's formula helped to calculate an ideal sample size. With a relatively large population as in this case, Cochran's formula is considered appropriate. The formula is shown in the equation 1 as follows:

$$n_0=(Z^2*P*Q)/E^2 \qquad \text{(Equation 1)}$$

Where: Z = confidence level of 95% (1.96)

E = margin of error (0.05)

P = proportion of the population (0.5)

Q = 1 – p (0.5)

$n_0$= Cochran's sample size recommendation

Fitting the above information in Equation 1, the minimum required sample size was 385 households of farmers. However, Cochran's formula can be adjusted for a smaller population, as shown in Equation 2.

$n=n_0/(1+((n_0-1))/N)$ (Equation 2)
Where: N = population size (1801 households)
n = adjusted sample size
Considering the target population of 1801 households, the minimum adjusted sample size was calculated as 360 farmers. Under each stratum (agroecological zone) 120 households are to be taken. Exactly 120 households from the Gasa district, 120 households from the Wangdue district and 120 from the Punakha district. Therefore, the results presented in this study are based on the analyses of data collected from 360 farmers.

**Sampling Technique**

The three districts were purposely selected to ensure the three ecological zones are located at different elevations and the climatic conditions are different in the three zones. Dividing the total 360 households into three ecological zones, each district/zone gets 120 households to acquire the proportionate number of households in each zone.

In the second stage, a minimum of one Gewog (sub-district) in each selected district was chosen. The selection of two gewogs was also purposive, based on the elevation of the ecological zones. This study covered a total of 12 villages under five sub-districts of three districts. The procedure of having a proportionate sample from each village is given in Table 1.

At the final stage, stratified sampling was employed. The selection of households was completely randomized (Batanero, 2015). The random function in Microsoft Excel 2019 "=RANDBETWEEN()" has been a handy tool to get the sample households when they were listed in serial numbers of alphabetic sequence of the names of the head of household. The household list of the 12 villages each time was put into serial numbers before random numbers were generated. Every village gets an equal share of 30 (8.33%) households. The stratified sample is shown in Table 2.

**Table 1:** Sampling Procedure

| Sl. Number | Screening Procedure | Number of household respondents |
|---|---|---|
| 1 | Initial list of population from the three agroecological zones | 1822 households |
| 2 | Exclusion of non-farming households | 1801 households |
| 3 | Three districts stratification | 120*3 = 360 households |
| 4 | Five sub-districts stratification | (120*1 + 60*4) = 360 households |
| 5 | 12 villages (four villages from each district) stratification | 30*12 = 360 households |

**Table 2:** Stratified random sampling (number; % in parenthesis)

| Dzongkhag | n (%) | Gewog | n (%) | Chiwog | n (%) |
|---|---|---|---|---|---|
| Gasa | 120 (33.33) | Laya | 120 (33.33) | Lungo | 30 (8.33) |
| | | | | Pazhi | 30 (8.33) |
| | | | | Naylu | 30 (8.33) |
| | | | | Chongro | 30 (8.33) |
| Wangdue | 120 (33.33) | Gangtey | 60 (16.66) | Gogona | 30 (8.33) |
| | | | | Kumbu | 30 (8.33) |
| | | Phobji | 60 (16.66) | Drangha | 30 (8.33) |
| | | | | Gangphel | 30 (8.33) |
| Punakha | 120 (33.33) | Kabjisa | 60 (16.66) | Petari | 30 (8.33) |
| | | | | Zabesa | 30 (8.33) |
| | | Dzome | 60 (16.66) | Tseyka | 30 (8.33) |
| | | | | Tana-Uesa | 30 (8.33) |

**Survey Questionnaire**

Designer solutions of Computer Assisted Personal Interviews (CAPI) as open-sourced material from World Bank Groups were used to administer survey questionnaires in the study (Handbook, 2020). The life cycle assessment approach of assessing food systems and the framework for assessing vulnerability to food systems were other tools adopted (Cucurachi *et al.*, 2019; Fraser *et al.*, 2005). This study adopted the semi-structured questionnaire consisting of closed and open-ended questions. The semi-structured questionnaire allowed to capture of additional information that arose during data collection and to be used in validating the quantitative data. The survey questionnaire is in four sections. Section one collected data on the socio-demographic profiles of the households. Section two surveyed food production and agricultural practices adopted in the regions. The third section has data on food and nutrition security status and the final section contains the climate change perception data from the respondents.

**Data Analysis**

Preliminary data from the field were downloaded from Survey solutions of CAPI and checked in detail for any missing, incomplete, or inconsistent responses. In case of any problematic response, the data was rectified via phone calls. The responses were incorporated in the data set, cleaned and coded in the Microsoft Excel spreadsheet version 2019 as an exercise of data management. A similar data management exercise was performed for the climate data from the NCHM and major food production data from NSB. The cleaned data set was then imported to IBM SPSS Version 25 for further analysis. Data were analyzed descriptively using mean, standard deviations, frequency, and percentage in the first section.

For the comprehensive analysis of food production, various data-driven techniques were employed to gain insights into the dynamics of agricultural output. Graphs and Pareto charts were utilized to establish patterns and identify key factors influencing food production. The Pareto chart proved instrumental in singling out the most significant contributors among the diverse array of food types produced, offering a targeted approach for improvement strategies. To delve deeper into the relationship between food production and climate change, a one-way ANOVA with post-hoc tests was conducted across three distinct agroecological zones. This statistical analysis aimed to quantify and compare the impact of climate change on agricultural productivity in each zone. Additionally, the assessment of food and nutrition security was undertaken using the new approach to assessing food security (Conforti, 2003).

To gauge climate change trends, trend lines for rainfall and temperature were plotted, providing a visual representation of environmental shifts. Furthermore, the Kruskal-Wallis test was applied to examine variations in climatic factors across the three agroecological zones, adding a robust statistical dimension to the analysis. This multifaceted approach offers a comprehensive understanding of the complex interplay between food production, climate change, and the critical aspect of food and nutrition security.

## RESULTS AND DISCUSSION

**Socio-Demographic Profile**

The socio-demographic profile of the respondents from the survey having five major variables with 13 characteristics that are related to food production in the three agroecological zones is illustrated in Table 3.

**Table 3:** Socio-demographic status

| Variable | Characteristics | Gasa n (%) | Wangdue n (%) | Punakha n (%) | Total n (%) |
|---|---|---|---|---|---|
| Gender | Male | 51 (42.50) | 56 (46.66) | 32 (26.67) | 139 (38.61) |
| | Female | 69 (57.50) | 64 (53.33) | 88 (73.33) | 221 (61.38) |
| Age Group | < 45 years | 72 (60.00) | 65 (54.16) | 78 (65.00) | 215 (59.24) |
| | > 45 years | 48 (40.00) | 55 (45.83) | 42 (35.00) | 145 (40.76) |
| marital Status | Married | 91 (75.83) | 95 (79.16) | 94 (78.33) | 280 (77.99) |
| | Unmarried | 15 (12.50) | 9 (7.50) | 9 (7.50) | 33 (8.97) |
| | Divorced | 5 (4.17) | 5 (4.16) | 14 (11.65) | 24 (6.52) |
| | Widowed | 9 (7.50) | 10 (8.33) | 3 (2.50) | 23 (6.25) |
| | Separated | 0 (0.00) | 1 (0.88) | 0 (0.00) | 1 (0.27) |
| Family Size | < 4 members | 39 (32.50) | 31 (25.83) | 41 (34.17) | 111 (30.83) |
| | > 4 members | 81 (67.50) | 89 (74.16) | 79 (65.83) | 249 (69.16) |
| Education | Literate | 53 (44.17) | 61 (50.83) | 56 (46.67) | 170 (47.22) |
| | Illiterate | 67 (55.83) | 59 (49.16) | 64 (53.33) | 194 (52.77) |
| | **Total** | **120 (100)** | **120 (100)** | **120 (100)** | **360 (100)** |

The research findings reveal significant insights into the demographic characteristics of individuals engaged in food production within the studied community. Gender dynamics play a crucial role, with women emerging as the predominant force, constituting 61.38% of the participants compared to men at 38.61%. This emphasizes the pivotal role of women in food production activities, while men tend to be attracted towards off-farm or non-agricultural pursuits women still prefer farming as their primary livelihood. Age is a determining factor in economic activity, as individuals below 45 years but above 18 years comprise 59.24% of the economically active population, this larger proportion of respondents actively contribute to food production. The study indicated that 57.2% of Bhutanese are engaged in agriculture, and the low-skilled labourers contribute 15.17% of GDP from agriculture (Pun & Shrestha, 2019). Marital status emerges as another key aspect, with a significant majority (77.99%) of participants being married. This suggests that agricultural activities are primarily undertaken by married individuals, highlighting the intertwining of family structure and agricultural engagement. Family size also appears to influence participation in agricultural activities, with households having more than four members constituting 69.16% of the sample. This larger family size indicates the availability of ample hands for agricultural tasks. With

60% of the total population of Bhutan being engaged in farming, food self-sufficiency at the household level has not been achieved (Pelzom & Katel, 2017). Furthermore, the educational composition of the sample is noteworthy, with 47.23% classified as literate and 52.77% as illiterate. This disparity in education levels underscores the need for targeted interventions and strategies that consider the diverse educational backgrounds within the community to enhance the overall effectiveness of agricultural initiatives. All this socio-demographic information indicates that the people in the region are engaged in food production, but the return is not sustainable. For sustainable food systems and enhanced food security there is a need to create avenue for farmers to continue doing farming, however, provide opportunities for them for innovative agriculture, mechanized farming techniques and climate smart agriculture. This will enhance food production in the region and provide sustainable livelihood to the farmers.

**Major Food Production Results**

The major foods identified as based on those widely used, grown in the maximum quantity and related to major food groups. Four cereals were identified as rice, maize, wheat and barley. Four major vegetables commonly grown in the region are spinach, beans, potatoes and radish. Similarly, the dairy products included are milk, butter, cheese and chugo (hard cheese) and the meat products included are beef, pork, chicken, fish, eggs and mutton. The aggregate food grown between 2000 to 2023 shows that the food basket is increasing and the share of food produced is also distributed uniformly. The study by Ingram (2011) mentioned that the assessment of the food systems approach particularly food production was suggested for the study of complex food security and global environmental changes. The total production of major food (19 in total) from the three regions of the study is illustrated in Figure 3.

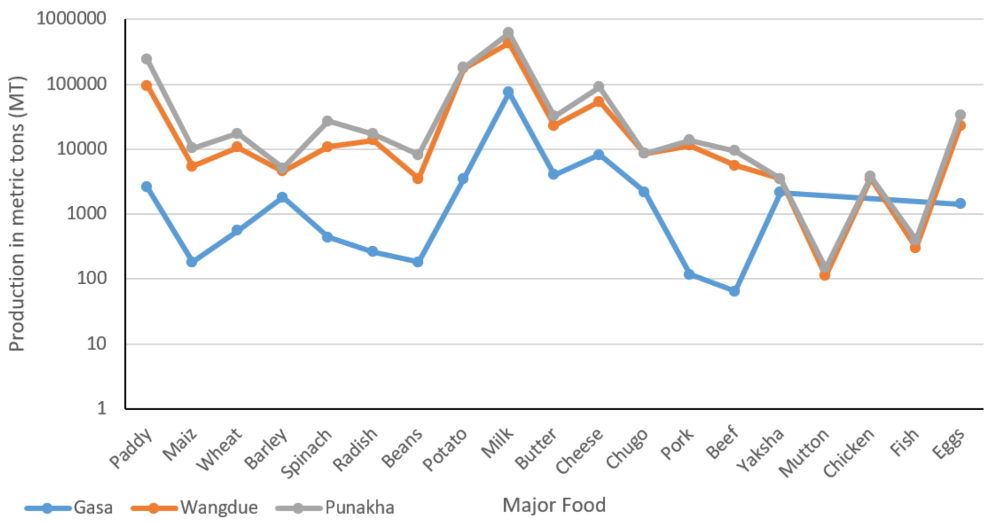


**Figure 3:** Major food production of common crops grown in the three regions measured in metric tons (MT)

Milk production has been highest in all three districts. Paddy had the second-highest growth combined in all three districts' total volume. However, the rest of the major food produced was less than 100000 metric tons. For the three districts, food like cooking oil and vegetables (for Gasa) is met through imports only. The food system stability is limited and therefore food insecure. With limited land holdings (including shared cropping land) of an average of 1.968 acres (Gasa 1.357 acres, Punakha 2.638 acres and Wangdue 1.904 acres) the food cultivation is limited. One of the constraints to mass food growth is limited land holding as reported by the farmers. There were sporadic cases of available land being left fallow for which no water supply, poor harvest, no farm labourers, the cost was higher than the return, and not an economically viable option. A Perato production of the major crops indicated in Figure 4 reflects the highest contributor and the lowest contributor and all those in between to make the total production as 100%. Milk is the highest contribution in the food basket while fish is contributing the list.

The Figure 5 indicates how is the production of the selected food items vary in terms of quantity (metric tons) between Gasa, Wangdue and Punakha. Major food production includes rice and vegetables. The largest contributor in the food basket however is milk. Agricultural practice is mostly integrated and subsistence farming. When nutrition was questioned, the respondents had a clear feeling that they get to eat nutritious food compared to the past. Nutrition-related diseases, particularly due to lack of calories were reported to be declining over the years. Food for commercial scale is limited to Punakha district where about 30% of farmers produce food for selling. Gasa had to import about 83% of the food it consumed in 2022. Wangdue mostly exports potatoes grown on a commercial scale but had to buy a lot of rice which is the staple food across all the regions. The recent phenomenon of youths migrating to urban areas, alternative livelihoods like cordyceps for Gasa and off-farm activities in Punakha and Wangdue impacted food production in the regions. The issue is the farm labour shortage. Wildlife causing harm to food production was

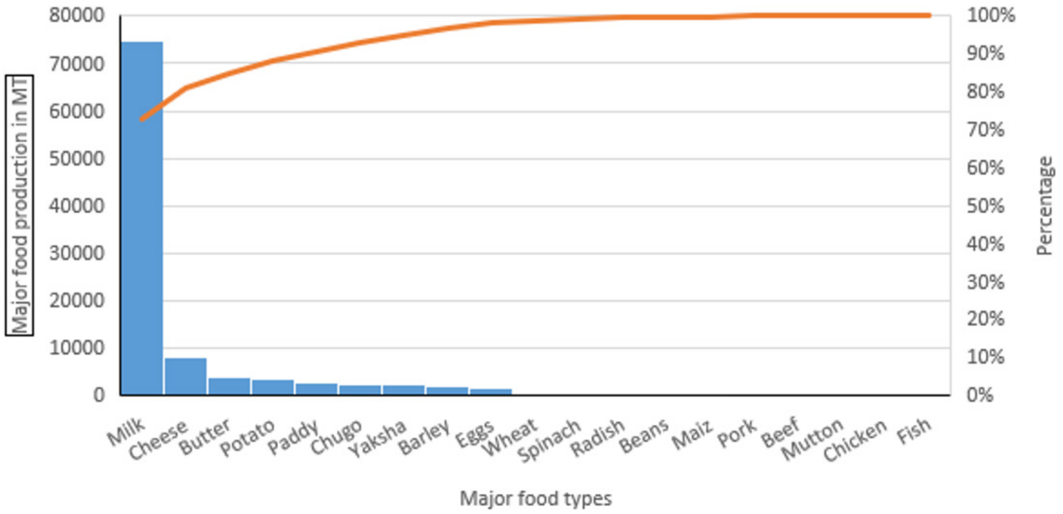


**Figure 4:** Pareto production of major food produced in metric tons (MT)in the three zones

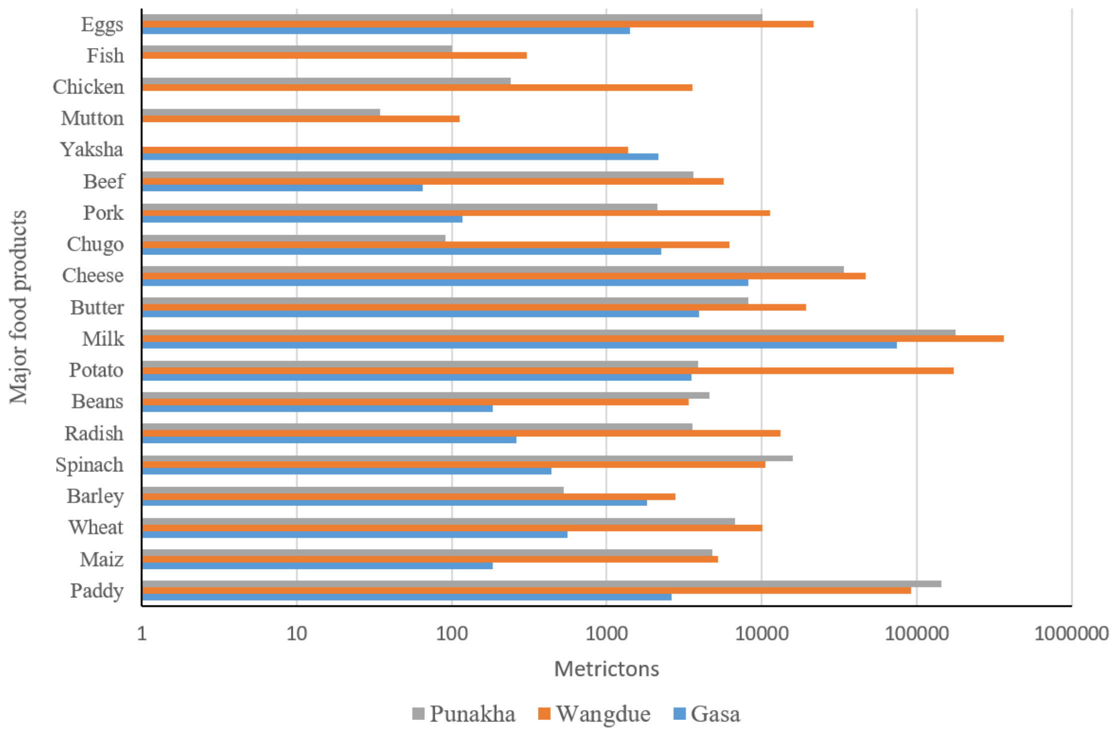


**Figure 5:** Percentage share of major food produced in the three agroecological zones

reported for Wangdue Dzongkhag. Gasa Dzongkhag has wild animals causing harm to human lives and houses but not to the food crops. Punakha Dzongkhag indicated not a major issue with human-wildlife conflict. There is also an issue of land fragmentation and land degradation The food systems, therefore, are complex mostly compensated with imports and limited export of food. The supply chain of food is through wholesalers and retailers. There also exists a food flow within the community in an informal but effective food barter system. Food security is a major concern in Bhutan, particularly in the study regions.

### Climate Trends in the Regions

The analysis of mean temperatures across three distinct agroecological regions, namely Gasa, Punakha, and Wangdue, reveals a consistent upward trend in temperature as reflected in Figure 6. This phenomenon underscores a broader pattern of climate change affecting these regions. Interestingly, Gasa exhibits a greater degree of temperature variability compared to Punakha and Wangdue, suggesting that the former is experiencing more pronounced fluctuations in climatic conditions. This heightened variability in Gasa may pose unique challenges for agricultural practices, requiring adaptive strategies to cope with the increased unpredictability. Despite regional variations, the overarching observation is the general warming trend across all three regions. This finding aligns with global climate change trends, emphasizing the urgent need for proactive measures to mitigate the potential impacts on agriculture and ecosystems in these agroecological areas. The implications of these temperature shifts warrant further research and policy consideration to ensure sustainable practices and resilience in the face of a changing climate. Greenhouse in cold areas like Gasa is proving useful for vegetable growers for self-consumption. However, the cost is high when all the infrastructure and labour input is needed. Cordyceps and aromatic NTFP (non-timber forest products) for incense making were more lucrative than vegetables growing in the regions. In low lands like Punakha and Wangdue, people choose to work in off-farm labours over farm work, in which the latter is tough work and has a lower wage rate.

The examination of rainfall patterns over the past two decades in three distinct regions-Gasa, Punakha, and Wangdue-reveals noteworthy trends and variations (Figure 7). Gasa, in particular, demonstrates a discernible upward trajectory in rainfall, signifying an increased trend over the analyzed period. Furthermore, Gasa exhibits the highest degree of variability in rainfall, suggesting a susceptibility to more significant fluctuations in precipitation. In contrast, both Punakha and Wangdue display fluctuating rainfall patterns across the years, with no clear trendline indicating a consistent increase or decrease. Notably, the rainfall trendlines in Punakha and Wangdue appear predominantly horizontal, reflecting relative stability in average precipitation over the 23 years. This observation raises important considerations for water resource management and agricultural planning in these regions, as the variations and trends in rainfall can significantly impact crop yields and overall ecosystem health. The contrasting patterns among the three regions underscore the localized nature of climate dynamics and emphasize the need for region-specific strategies to address the challenges posed by changing rainfall patterns. Further research and adaptive measures are essential to enhance resilience and sustainable resource management in the face of evolving climatic conditions.

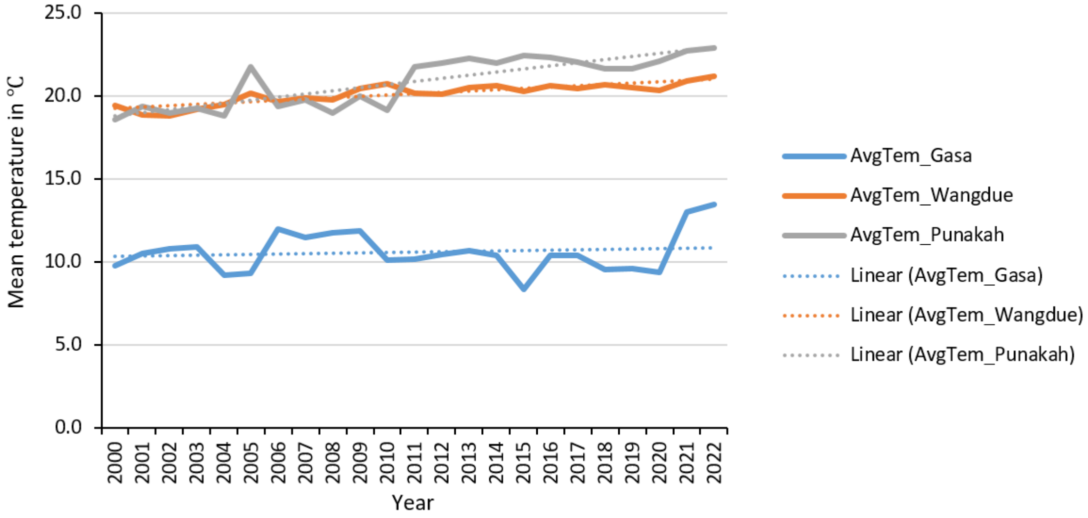


**Figure 6:** Temperature trend in the three climatic zones

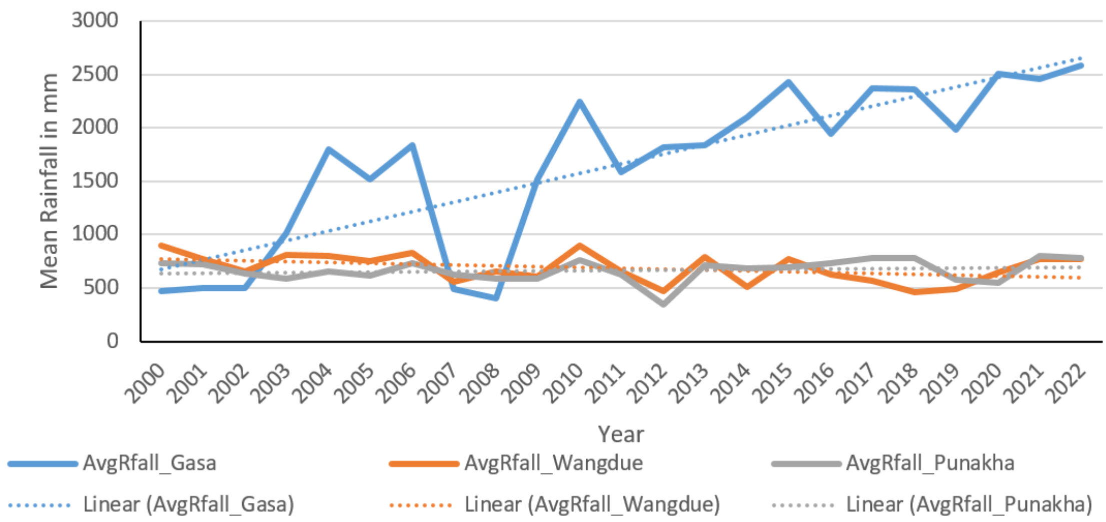


**Figure 7:** Rainfall trend in the three climatic zones

To substantiate the observed climate change trends derived from quantitative data, we complemented our analysis with a qualitative exploration of respondents' perceptions. The convergence of these two data sources strengthens the robustness of our findings. Most participants across all three agroecological zones unequivocally affirmed the reality of climate change, aligning with the objective temperature and rainfall trends identified through our quantitative analysis. Notably, when prompted to identify the primary cause of climate change, a remarkable consensus emerged among respondents. The data revealed a striking 85% agreement attributing climate change to human activities, indicating a pervasive awareness of anthropogenic influences on the environment.

Further insights were gleaned from a radar chart representation, illustrating the distribution of responses among the provided options. A mere 10% of participants attributed climate change to natural changes, underlining the prevailing acknowledgement of human impact. In contrast, a marginal 3% ascribed climate change to unappeased deities, and a minimal 2% linked it to religious reasons. This refined breakdown not only highlights the predominant perception of human-induced climate change but also offers a glimpse into the diversity of beliefs regarding the causative factors of climate change.

These findings underscore the need for targeted educational and awareness initiatives to address misconceptions and cultivate a shared understanding of the anthropogenic contribution to climate change. Moreover, the high percentage attributing climate change to human activities accentuates the importance of adopting sustainable practices and policies to mitigate further environmental degradation. The triangulation of quantitative and qualitative data provides a comprehensive perspective on the climate change discourse, laying a foundation for informed decision-making and adaptive strategies in the face of this pressing global challenge. Table 4 indicates the perception of the respondents towards the cause of climate change. Similarly, upon enquiring the respondents about if climate change is having a detrimental impact in their lives, majority voiced out saying there is an visible impact of climate change as reflected in Figure 8.

A Kruskal-Wallis test was conducted to examine the effect of Climate Change in 3 AEZs (H)=13.53, df=(2), p<.05. The Mean Rank for Gasa [168.53], for Wangdue [194.60], and Punakha [178.37]

**Figure 4: Causes of CC: local perception**

| Dzongkhag | Human Activities | Natural Changes | Un-appeased Deities | Religious Reasons | Total |
|---|---|---|---|---|---|
| Gasa | 66 | 35 | 14 | 5 | 120 |
| Punakha | 71 | 36 | 10 | 3 | 120 |
| Wangdue | 65 | 40 | 11 | 4 | 120 |

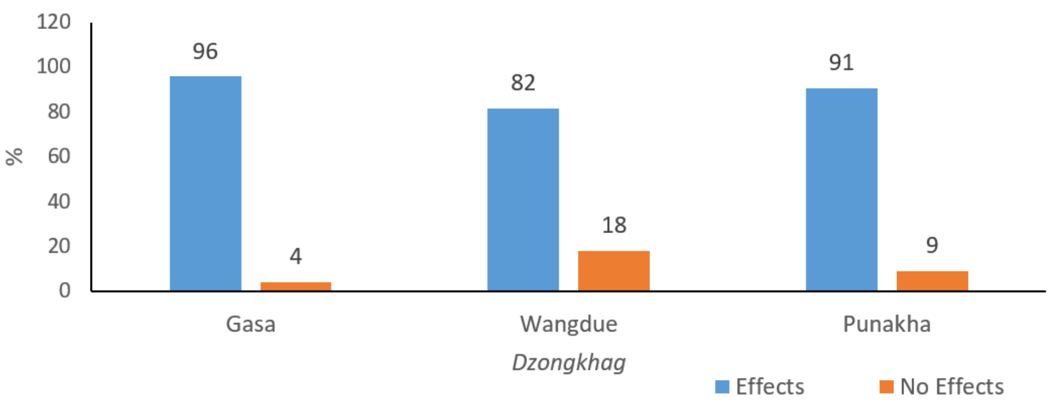


**Figure 8:** Perception of Impacts of CC in the regions

Perception of CC affecting food production is found to be high across all 3 AEZ. So Non-parametric Kruskal-Wallis test for inferential statistics was performed. Similar results were found in assessing the impacts of Climate Change in different AEZs of India (P Singh *et al.*, 2020). The data were tested for normality and found to be not normal. So non-parametric test for inferential statistics has three groups qualified for the Kruskal-Wallis test. The results indicated a significant difference in food production across the Agroecological Zones. While there is a significant difference in food production in all three AEZs, there are also unsustainable food systems. For instance, respondents from Gasa voiced that the food supply during COVID-19 was frequently disconnected and people from Gasa panicked several times during the pandemic.

A one-way ANOVA was performed to compare the effect of climate change in the three Dzongkhag on food production. A one-way ANOVA revealed that there is a statistically significant difference in food production (paddy) between groups ($F(2, 45) = 43.25$, $p < .05$). Post Hoc tests (Tukey's HSD Test) for multiple comparisons found that the mean value of food production (paddy) was significantly different between Punakha and Gasa (p<.05, 95% C.I. = 6529.79, 11202.38). The findings are aligned with the studies of Raju *et al.* (2020) and Vasenev *et al.* (2015) where different zones with different climate changes affect soil quality and thereby food production differently.

A production-consumption coordination assessment for major food in the regions as recommended in China for ensuring food security (Wu *et al.*, 2016). While the coordination is effective for case like Big nation China, same is irrelevant in this study with smaller scale like this. With climate change, food supply gets disrupted. Food suppliers for example use chemicles to ripen or mature food faster to meet the demand that might lead to health risks. A study by Uche, *et al.*, (2023) found risks and pathogenic effects of consuming bananas ripened by use of calcium carbide to pregnant mother and baby. However, stated that a technically appropriate way of food formulation can improve nutrition quality of consumers (Olosunde, *et al.*, 2023). Food production and food flow is having detrimental implication due to climate change. When the farm labour shortage, land fragmentation, land degradation and poor technology and innovation in food production, climate change is aggravating the issue further pushing farmers towards a food insecure state.

## CONCLUSION

Food systems are highly fragile with limited technology and innovation, and food security is a concern in the regions aggravated with climate change. Farm labour shortage, land fragmentation and limited farming technology are disabling the commercial level of food production. Climate change is a major concern for food security in all the regions. Yak farming is hampered in Laya, rice production declined due to drying or damage of irrigation channels and pests on potatoes in Wangdue are all attributed to climate change. However, the nutrition of the food the present generation is consuming was reported to be healthier than what their parents could consume. There is an implication of per-capita food production decline over the years causing the food system to be import driven. Diversified livelihoods of farmers make the already degraded land to be left unattended. For now, the farmers in all three regions have poor food systems with high food prices and low local production, leading to food insecurity.

Implement a Systematic Land Leasing Program (SLLP) to optimize land utilization and enhance the economic viability of mechanized farming, a systematic land leasing program should be established. Small parcels of land from multiple farmers can be leased to individual or group commercial farmers. This consolidation of land resources allows for economies of scale in production, making it economically feasible for farmers to invest in mechanized farming practices. Government support and incentives for both landowners and commercial farmers can further encourage participation in such programs, contributing to increased agricultural productivity.

## RECOMMENDATIONS

Addressing water scarcity through climate-smart agriculture practices is crucial for sustainable food production. Providing lead and commercial farmers with technology such as drip irrigation and sensor sprinklers in greenhouses can significantly mitigate water shortages. The government should invest in training programs to educate farmers on these practices and provide financial support for adopting water-efficient technologies. Integrating climate-smart agriculture makes the agricultural sector more resilient to climate variations, ensuring consistent food production while minimizing environmental impact.

Support crop diversification and livestock management. Encouraging the cultivation of high-yielding seeds for both local consumption and export is vital for nutritional security. Government support in providing high-yielding seeds to commercial farmers fosters a robust agricultural sector. Additionally, the revival of wheat cultivation for food, rather than just fodder, enhances food diversity. Implementing advanced storage technologies is essential to manage large-scale potato cultivation to prevent rotting and sprouting. Furthermore, promoting dairy product diversification and establishing milk processing stations in sub-districts can stimulate the dairy industry. Minimizing free grazing and encouraging stall feeding for a manageable number of high-quality cattle preserves arable land and ensures sufficient manure for crop growth. Implementing these interventions alongside supportive policies will collectively bolster food security in the region.

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