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Adapting to Social–Ecological Risks to the Conservation of a Muskmelon Landrace in India

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Abstract: Crop landraces are vanishing alarmingly worldwide, posing serious risks to the livelihoods of the resource-poor farmers; this study, conducted using 'vulnerability' and 'resilience theory' frameworks, sought to delineate social–ecological, climatic and policy hindrances to the conservation of a muskmelon landrace '*Jaunpuri Netted*' traditionally grown in eastern Uttar Pradesh, India. Our results showed that the blue bull menace, market constraints and erratic rainfall have gradually emerged as severe stresses to the conservation of this muskmelon landrace. Yet, a set of enablers including relative ease in crop management, pleasant fruit taste, perceived livelihood opportunities and the cultural legacy seem to offset these stresses, at least partly, keeping the farmers engaged in muskmelon cultivation. The Tobid regression analysis revealed that educated farmers with large landholdings were likely to grow muskmelon on relatively small acreages, and that market constraints, blue bull menace and erratic rainfall are the major future risks to the muskmelon-based livelihoods. A growing obsession with higher fruit yields has led to the virtual eclipse of traditional crop management practices, further enhancing the vulnerability of muskmelon growers. Addressing these challenges requires some major changes to the ways in which the muskmelon crop is managed and traded. While muskmelon growers need to revisit the present chemical-intensive practices, adequate research and policy support remain requisite to unveiling the unique nutraceutical properties of this muskmelon landrace, promoting organic farming, reviving seed-based business opportunities, and creating strong market linkages to enhance the livelihood resilience of the muskmelon growers.

Keywords: adaptive practices; genetic erosion; livelihood resilience; melon diversity

Citation: Singh, A.; Singh, R.K.; Kumar, N.; Kumar, S.; Sheoran, P.; Singh, D.; Kumar, S.; Sharma, P.C. Adapting to Social–Ecological Risks to the Conservation of a Muskmelon Landrace in India. *Sustainability* **2022**, *14*, 9880. https://doi.org/10.3390/su14169880

Academic Editor: Uta Schirpke

Received: 13 July 2022
Accepted: 8 August 2022
Published: 10 August 2022

1. Introduction

Crop landraces play a pivotal role in sustaining the farmers′ livelihoods [1,2], and in enhancing agro-ecosystem resilience to external shocks [3,4]. In addition to improving the food and nutrition security of the smallholder farmers [5], they also ensure stable yields under sub-optimal and low-input conditions compared to modern cultivars [6,7]. Crop landraces constitute an important source of novel genes and traits for improving crop tolerance to insect pests and diseases [8], and to abiotic stresses such as drought and salinity [9,10]. Available evidence suggests that landraces will play an increasingly important role in addressing the current and future food security challenges arising due to climate change impacts [2,11]. Despite these and other benefits such as provisioning and regulation of ecosystem services and functions [7], the last few decades have witnessed an alarming loss of crop landrace diversity across the globe [12–14]. The relentless disappearance of landraces signifies the forever loss of genes that have evolved over millennia from the plant genome [11]. Notwithstanding the fact that resource-poor farmers, especially those in the developing countries, still rely heavily on locally-adapted landraces for their livelihoods [1], their unabated erosion is worrying [4,6] with wide-ranging implications for the availability and quality of food [15], and the ecological sustainability [16]. The fact that ex-situ gene banks represent only a fraction of the genetic diversity of a species and virtually halt the genetic evolution has led to a strong focus on *in situ* conservation in natural habitats and/or in farmers′ fields [13,17].

Changes in land use, caused for instance by transitioning from traditional crop-livestock mixed systems to input-intensive monocultures, can have profound adverse impacts on local livelihoods [18]. Increased household incomes from such changes often come at the expense of biodiversity loss and impaired agro-ecosystem resilience [19]. Accelerated loss of traditional farming systems and practices, resulting from agricultural transformation, erosion of traditional knowledge and cultural values, lack of incentives for intangible ecosystem services, and out-migration for better livelihood opportunities remains a significant global concern [20,21]. In India, the early signs of natural resources degradation and the concomitant loss of traditional agricultural systems were noticeable even during the 19th century [22]; this trend continues unabated, albeit with a greater intensity, causing a tremendous loss of indigenous crop diversity and abandonment of traditional farming practices [19,22]. Available evidence suggests that the adoption of modern cultivars and farming practices has also hastened the depletion of agro-biodiversity and associated traditional knowledge in eastern Uttar Pradesh, India (study region) [15,23,24], posing livelihood risks to the local resource-poor farmers who are also increasingly grappling with climatic and social–ecological risks [25]. A shift from subsistence to commercial farming may not always be the sole driver of agro-biodiversity loss; pervasive land use, reduced social resilience, declining interest in farming, flawed policies and climate change impacts are other prominent risk multipliers [26]. The loss of biodiversity and ecosystem services is intricately linked, and has cascading effects on livelihoods, social resilience, and cultural heritage [27].

Muskmelon (*Cucumis melo* L.) is widely grown as a warm-season fruit vegetable in different parts of the world. Fruits attain premium quality when grown in light textured soils under warm and sunny conditions [28]. In India, muskmelon is cultivated over an area of 54,000 ha with a total production of about 1231 thousand metric tons. Uttar Pradesh is the largest muskmelon-producing state of India accounting for ~45% of the total muskmelon production [29]. Besides major use as a dessert fruit, muskmelon seeds are valued as rich sources of protein and oil [30]. India has a considerable genetic diversity in melons for fruit quality traits such as shape, size, colour and taste from the different parts of the country [8,31]. Locally-adapted muskmelons are widely grown in several states of India including the study state of Uttar Pradesh from where landraces such as '*Jaunpuri Netted*', '*Lucknow Safeda*', '*Mau*', and '*Kajari*' have been reported [32]. Notwithstanding a rich melon diversity in India, most of such landraces remain uncharacterized for fruit quality traits and biochemical composition; key requisites to sensitize the conservators and consumers about their significance. Crop landraces and traditional farming systems are so inextricably linked that they cannot be seen in isolation. As farmers′ socio-ecological ethos and practices remain deeply embedded into landrace conservation [6], it remains vital to understand how social–ecological changes and shifts in traditional farming practices affect their conservation. Muskmelon landrace '*Jaunpuri Netted*' is believed to have been grown in the Jaunpur district of Uttar Pradesh, India for a long time; however, except for a few blog reports describing its sublime flavour and sweetness [33,34], the recent trends in the conservation of this landrace, farmers′ perception and the emerging stressors largely remain unknown. A better understanding of the current state of management and the constraints may help develop future plans for the sustainable cultivation of this landrace. Consistent with these facts, this study was carried out with the following objectives: (i) to delineate the trends in conservation and utilization of muskmelon landrace '*Jaunpuri Netted*'; (ii) to identify social–ecological stressors posing risks to muskmelon conservation and the associated traditional practices; and (iii) to suggest some adaptive pathways for sustained conservation and enhanced livelihood resilience of the muskmelon growers.

2. Conceptual Framework

Some practitioners tend to be overly focused on human dimensions while studying the vulnerability–adaptation nexus [35]. Contrarily, the advocates of resilience theory emphasize a systems approach to discern the interplay between them [36,37]. While both of these approaches are important to understanding the farmers' vulnerability, they have some obvious limitations when viewed separately; this is because vulnerability is caused by an array of environmental risks; its severity often greatly depends on social–ecological resilience [38] (Figure 1). Farmers are an integral component of a dynamic agro-ecosystem [39], regardless of the social–cultural settings, such that their perceptions of vulnerability are not governed by a single factor. Oftentimes, farmers are instantaneously exposed to an altogether new stressor leading to enhanced vulnerability; likewise, quite often, farmers bear the brunt of multiple stressors emanating from social, ecological, climatic and policy realms [25,38,39]. Under such conditions, management strategies recommended by the research and policy institutions may be of little help, leaving the farmers in a more vulnerable situation [40]. Adaptive capacity is often defined as the sum total of farmers' resource endowments to cope with the multiple risks [41] that, in turn, is governed by a wide range of socio-economic, cultural and ecological factors [41,42]. Taking insights from these studies, we defined farmers' adaptive capacity as the extent to which they invest their knowledge and resources in conserving the muskmelon landrace '*Jaunpuri Netted*' for better livelihoods (Figure 1). Resilience refers to the capacity of a social–ecological system to maintain its structure and functions when exposed to a variety of extraneous perturbations [43,44]. In the context of the present study, we considered resilience as enhanced livelihood opportunities provided by a set of enablers in the face of increasingly adverse social–ecological, climatic and policy stressors (Figure 1).

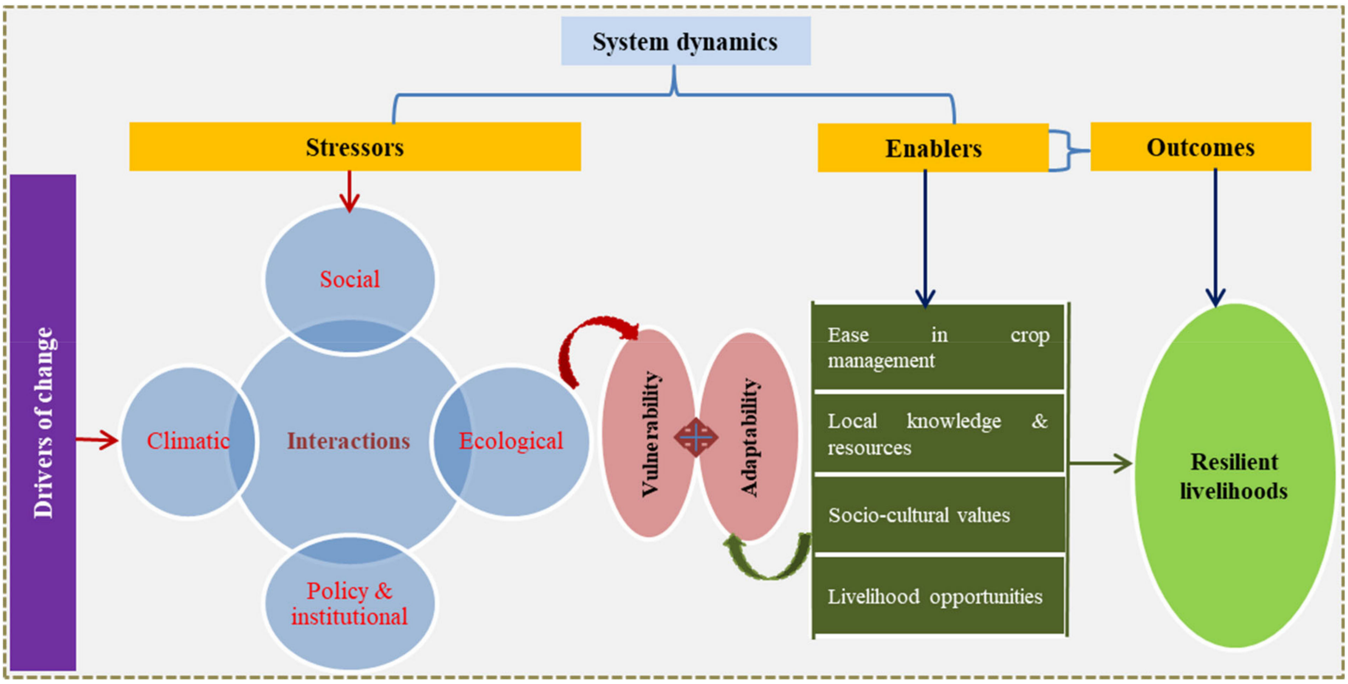

Figure 1. Conceptual model indicating perceived multiple stressors and motivational enablers relating to conservation of muskmelon landrace and livelihood perspective.

3. Research Methodology

3.1. Study Area

The study was carried out in Jamaitha Village of Jaunpur district of Uttar Pradesh state, India (25°43′58.9″ N 82°43′49.1″ E). Lying in the Middle Gangetic Plains Region, the district receives a mean annual rainfall of ~1100 mm; a bulk of which (~90%) occurs during June-September [45]. Diminishing soil fertility and fresh water availability, soil and groundwater salinity, the poor adaptive capacity of the local farmers, and lack of better marketing facilities are the major hindrances to sustainable crop production in the district [24]. While rice (*Oryza sativa* L.), maize (*Zea mays* L.), pearl millet [*Pennisetum glaucum* (L.) R. Br.], pigeon pea [*Cajanus cajan* (L.) Millsp.] and black gram (*Vigna mungo* L.) are the major summer season (*Kharif*) crops; wheat (*Triticum aestivum* L.), pea (*Pisum sativum* L.) and chickpea (*Cicer arietinum* L.) are the main winter season (*rabi*) crops in the district. Cash crops like sugarcane, fruits such as mango and guava, and vegetables are also grown [45]. The study village, Jamaitha, has a population of 7813 consisting of 4055 males and 3758 females. Of the total population, 2723 people are engaged in work activities with 62.87% of the workers engaged in 'Main Work' (Employment or earning > 6 months) and the rest (37.13%) involved in 'Marginal Activity' providing livelihood for <6 months. Of 2723 workers engaged in the Main Work, 991 are cultivators (owner or co-owner) while 336 are agricultural labourers [46]. Agricultural lands of the study village are prone to soil erosion, are marginally alkaline (soil pH up to 8.50) and deficient in nitrogen and phosphorus [47].

3.2. Sampling Design

The study was conducted during years 2016 to 2019. Initially, the broad trends in muskmelon conservation were discussed with the officials of the District Agriculture Department, Subject Matter Specialists of the local Krishi Vigyan Kendra (KVK, Jaunpur; Farm Science Centre), and some local people well aware of the impending threats to muskmelon landrace '*Jaunpuri Netted*' traditionally grown in Jamaitha and some adjoining villages of Jaunpur district; these deliberations gave us food for thought: issues in muskmelon cultivation and changes in adaptive practices needed to be examined to reach to a definitive conclusion. Subsequently, we paid three visits to the study village during the second and third weeks of April 2016 in order to acquaint ourselves with the changing social–ecological dynamics and the emerging stressors vis-à-vis muskmelon conservation. During the first two visits, the aims and the probable outcomes of the study were shared with the prospective study respondents. An inclusive Prior Informed Consent (PIC) was also obtained from the muskmelon growers willing to participate in the study to publish the results. The study village, Jamaitha, in the Sirkoni Developmental Block of Jaunpur district, Uttar Pradesh (UP), India was purposively selected; given the fact that muskmelon landrace '*Jaunpuri Netted*' is almost exclusively grown in this village. In the next stage of the study, rapport building was carried out with the muskmelon growers. Finally, based on consultations with some village elders and key respondents, a list of 60 farmers to be interviewed was prepared: continuous muskmelon cultivation over the past 10 years and permanent residences in the study village were the two criteria for sampling the study farmers. Additionally, we also purposively selected 5 key respondents on account of their rich experience (>40 year) in muskmelon cultivation to ensure that major trends and farmers' perceptions vis-à-vis changing dynamics in the conservation of this landrace were adequately and fairly captured, and that there was no subjective bias. The inclusion of key respondents also helped us to gain a better understanding of recent trends in muskmelon cultivation during field transect walks and focus group discussions (FGDs).

3.3. Data Collection

We adopted both qualitative and quantitative data collection techniques for recording the livelihood risks and adaptive strategies into vogue among the muskmelon growers [25,48]. A qualitative approach was applied to record the observations during transect walks and the FGDs. A total of four transect walks were carried out prior to personal interviews during the second week of April 2017 in the presence of key respondents (n = 3–5) and muskmelon growers (n = 8–12) to acquire a fair understanding of the local topography, cropping patterns, spatial-temporal changes and the general features of muskmelon fields; it also helped us in developing and pilot-testing the interview schedule for personal interviews; this exercise helped us in omitting ambiguous questions, improve the language and to finalize the variable scoring without any bias. Quantitative observations were recorded by personal interviews using an interview schedule during the third week of April 2017. The interview schedule had four sections dealing with growers' socio-economic profile, perceived stressors, enablers and livelihood opportunities. While the first section had open-ended questions on socio-economic variables, the remaining sections comprised closed-ended statements for measuring the farmers' perceptions of stressors, enablers and livelihood dimensions in muskmelon cultivation. Four different FGDs were also conducted with key respondents and the muskmelon growers (n = 10–15 in each FGD) to understand and record their opinions and ideas in relation to past and current agronomic practices, traditional uses and the changing decadal dynamics in muskmelon cultivation (1990–2017); this enabled us to better contextualize on-the-ground-realities by collating the farmers′ perceptions with the opinions emerged during the FGDs.

3.4. Measurement of Variables

3.4.1. Socio-Economic Variables

Available evidence suggests that personal profiles and the prevailing socio-economic settings greatly influence the farmers′ adaptive and decision-making abilities in a given community cf. [49]. Such variables assume even a greater significance in marginal areas where resource-poor farmers often heavily rely on local resources to cope with multiple stresses [42,50]. We considered farmers′ age, experience, education, annual income (in INR), total landholding, the area under muskmelon and extension contacts as the prominent socio-economic variables determining their vulnerability and adaptive capacity. Each variable was measured using a well-defined scoring scale (Table S1 in online resources).

3.4.2. Stressors, Enablers and Livelihood Opportunities

Farmers′ perceptions of stresses impacting their livelihoods greatly influence location-specific adaptation strategies for the conservation of biocultural resources [51]. In this study, farmers′ perceptions of stressors taking a toll on their muskmelon-based livelihoods were recorded using the following variables: incidence of blue bulls, erratic rainfall, declining interest in farming including muskmelon cultivation, market constraints and poor institutional support; these variables were chosen after thoughtful deliberations during rapport building and transect walks; these variables were measured using a three-point scale: based on farmers' perception, scores of '3', '2' and '1' were assigned to 'high', 'moderate' and 'low' impacts of different stressors, respectively. 'Enablers' are a set of factors—structural, operational and cultural [52]—that enhance the adaptive capacity of the farming communities to cope with various social–ecological risks [53]. In the present case, we defined 'enablers' as a set of socio-cultural and crop-specific factors, keeping the growers interested in muskmelon conservation even in the face of steadily magnifying risks. Based on initial discussions with the key respondent and the farmers, 'cultural heritage', 'social prestige', 'short crop duration', 'ease-in-management', 'pleasant fruit taste' and the 'livelihood support' were included as the enablers, measured using a three-point scale: scores of '3', '2' and '1' were assigned to the enablers perceived to be of 'high', 'moderate' and 'low' support, respectively.

3.4.3. Satellite Image Processing

Satellite imageries from Landsat 5TM, 7 and 8 [54] were acquired and processed to delineate the temporal reductions in muskmelon crop area over a period of 25 years (1992–2017), at an interval of 5 years; this also helped us in collating the farmers' perception regarding a decrease in muskmelon crop area over time. Satellite imageries for the month of May, the peak period of fruiting, were accessed for the years 1992, 1997, 2002, 2007, 2013 and 2017, and processed using the software Arc GIS v. 10.3. Both supervised and unsupervised techniques of classification were used for distinguishing different types of land uses. Furthermore, the normalized deference vegetative index (NDVI) technique was also employed to distinguish the perennial vegetation from the field crop(s). It is pertinent to mention that muskmelon is the only major crop grown during the April–June period in the study village.

3.5. Data Analysis

3.5.1. Statistical Tests

The data were entered into a spreadsheet and structured thematically. Summary statistics (mean and frequency) were computed for each set of variables. Principal Component Analysis (PCA) was applied to reduce the dimensionality and to discern the key trends in data. The suitability of data for PCA analysis was tested by Bartlett′s test of sphericity using *R* software (version. 3.6.1, accessed from crain.r.project.org). The Kruskal–Wallis Analysis of Variance (ANOVA) by ranks was used to test the significance of mean ranks for stressors and enablers. Bonferroni-Dunn test was sued for multiple comparisons of rank sums. All the statistical analysis and graphics were carried out using the *R* software (version 4.2.1, accessed from crain.r.project.org) [55].

3.5.2. Tobit Regression

We ran a Tobit regression model to quantify the positive and negative impacts of different socio-economic variables, stressors and enablers on the response variable i.e., the 'extent of conservation' of the muskmelon landrace '*Jaunpuri Netted*'. The response variable (y_i), in terms of area under muskmelon to the total landholding for the *i*th farmer, was treated as the continuous variable; however, the response variable ranged between '0' to '1' for different farmers, there was a boundary ($y_i \in (0, 1)$. Under such conditions- a continuous variable with lower and upper limits [56] Tobit regression is considered an appropriate regression technique. The regression equations used are given below:

$$y_i{}^* = z_i'\beta + \mu_i; \;\; \mu_i|x \sim N(0, \sigma^2) \tag{1}$$

$$y_i = \begin{cases} y_i{}^* \; if \; y_i{}^* > 0 \\ \text{otherwise } 0 \end{cases} \tag{2}$$

Here, y^* and y_i are the latent and observed variables, respectively. z_i is the set of explanatory variables- socio-economic attributes of the study farmers, perceived stressors and perceived enablers- assumed to be influencing the extent of conservation (response variable). B is the vector of the unknown parameter to be estimated. μ_i is the random error with a normal distribution (zero mean and constant variance σ). The likelihood function of the model is:

$$L(\beta, \sigma|y_i, z_i) = \prod_{y_i{}^* > 0} \frac{1}{\sigma} f\left(\frac{y_i - z_i'\beta}{\sigma}\right) \prod_{y_i{}^* \leq 0} F\left(\frac{-z_i'\beta}{\sigma}\right) \tag{3}$$

where, $f(.)$ and $F(.)$ are density and cumulative distribution functions, respectively.

Marginal effects, a derivative of the estimated Tobit model, are used to examine the effects of changes in the explanatory variables. A change in 'z' affects (1) the conditional mean of y^* in the positive part of the distribution, and (2) the probability that an observation will fall in that part of the distribution. The marginal effects to measure the contribution of different variables [57] in estimating the 'extent of conservation' (response variable) can be explained as:

$$\text{Marginal effect } = \frac{\partial E(y|z)}{\partial z} = \text{prob}(y > 0) \, \frac{\partial E(y|z, y\rangle 0)}{\partial z} + E(y|z, y > 0) \frac{\partial \text{prob}(y > 0)}{\partial z} \tag{4}$$

Key results of the study were shared and discussed with the muskmelon growers to draw conclusive inferences.

4. Results

4.1. Socio-Economic Profile of Muskmelon Growers

Our study respondents had an average age of 50.98 years and an average experience of 34.37 years. A majority of them (31.67%) had received primary schooling followed by education up to high school (25%); 8.33% of them did not receive any formal education. A strong majority of the study participants (93%) were small and marginal landholders (total landholding < 2.0 ha) and heavily dependent on farming for bread and butter; 35% solely on crop production, 53.33% on crops and allied activities (e.g., dairying), and 11.67% on three or more sources (e.g., salaried employment) in addition to farming and ancillary activities. The area under muskmelon was <0.40 ha for 50% of the farmers; 30% of them grew muskmelon on a 0.40–0.80 ha area and the rest (20%) on a relatively large area (>0.80 ha). In so far as extension contacts were concerned, 55% of them had recently come in contact with a particular extension/development agency, and 45% with two or more such agencies; however, it is pertinent to mention that farmers' extension contacts were rather intermittent; mostly once every 3–4 years.

4.2. Traditional Knowledge and Practices

Although none of the study farmers were familiar with the exact origins of muskmelon cultivation in the study village, two of the key respondents (aged > 75 years) opined that muskmelon is being grown for at least four generations in the study village; implying that this practice was about a century old. About 35% of the respondents said that crop was earlier also grown in some of the neighbouring villages. The different stages of muskmelon crop (including phenotypic attributes of *Jaunpuri Netted landrace*), early vegetative growth (Figure 2a), immature fruits (Figure 2b), mature fruit (Figure 2c), a blue bull herd (Figure 2d), and sale on the local village market (Figure 2e,f) are shown in Figure 2. All the respondents opined that pleasant fruit taste and a sense for cultural heritage were the best explanations for the sustained conservation of this landrace. The respondents aged > 60 years informed that crop would ordinarily be sown from mid-January to mid-February using the home-grown seeds; the highest yields and the best quality fruits were obtained from the crop sown shortly after '*Makar Sankranti*' festival falling on 14 or 15 January; this was partly because early sowing ensured a healthy crop growth. Additionally, January sown crop would ensure staggered fruit pickings for over a month compared to a considerably short (15–20 days) harvest window from the late sown crop. The farmers would carefully pick the best quality fruits, usually from the first harvest, to save the seeds for the next crop. About 100 fruits would provide sufficient seeds for an acre of land. The fields, kept fallow the previous season, were carefully prepared and the crop meticulously nurtured using the home-grown organic inputs.

4.3. Stressors and Enablers in Muskmelon Conservation

Our findings revealed that social–ecological risks to muskmelon cultivation have steadily magnified over the past two decades. All the study respondents opined that blue bulls (locally called *nilgai*; *Boselaphus tragocamelus*), and sometimes other stray animals, were increasingly posing risks to profitable muskmelon cultivation; 95% of them reported 'moderate' adverse impacts of the blue bulls (Figure 2d). Likewise, moderate adverse impacts of erratic rainfall on fruit yield and quality every two to three years were perceived by ~73% of the respondents. Notably, about 47% of the respondents (particularly those aged > 60 years) perceived a noticeable decline in organoleptic fruit qualities over the past 8–10 years; they remarked that changing climatic conditions and crop management practices often cause marginal-to-moderate reductions in fruit firmness, aroma and flavour. Nearly 92% of the study farmers said that the declining interest of village youth in muskmelon farming had low-to-moderate impacts on household livelihoods; the remaining 8% adjudged it to be a serious concern (Online Supplementary Table S3). Market constraints were perceived to have low and moderate impacts on profits by 38.3% of the farmers each. The study respondents were unanimous about the declining area under muskmelon, and about eroding social institutions and traditional values associated with muskmelon cultivation. Our study farmers identified six different enablers, providing them with some respite from the aforementioned stressors. Notably, short crop duration (88.3%), ease-in-management (95%), pleasant fruit taste (88.40%) and livelihood support (95%) were perceived to be of moderate-to-high value, keeping the growers interested in muskmelon conservation in spite of magnifying risks (Online Supplementary Table S3).

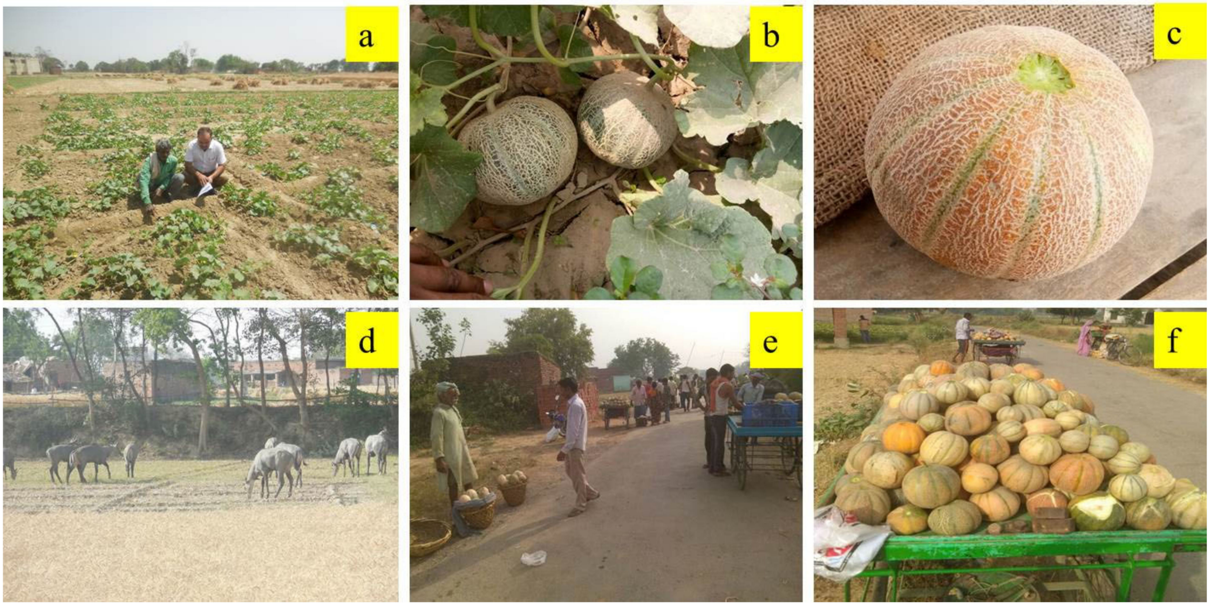

Figure 2. Different stages in the muskmelon crop cycle. Crop in the early vegetative growth stage (**a**), immature fruits (**b**), ripe fruit (**c**), a blue bull herd (**d**), fruit sale on village market (**e**,**f**). Photographs source: Anshuman Singh.

Based on Kruskal–Wallis test, blue bull menace and poor institutional support were identified as the most and the least significant stresses, respectively, facing the muskmelon growers (Figure 3a). Similarly, ease-in-management, pleasant fruit taste and livelihood supports were found to be the most prominent enablers (Figure 3b). The efficiency of PCA in reducing the dimensionality was evident in the first five components (Eigen value $\geq$ b) explaining a reasonable summary (~70%) of the data (Online Supplementary Table S4). Erratic rainfall (15.51%), market constraints (15.98%), poor institutional support (17.86%) and social prestige (18.72%) were the highly weighted variables on Dim-1 (Eigen value = 2.55, variance = 21.21%), cultural heritage (20.34%) on Dim-2 (Eigen value = 2.07, variance = 17.25%), blue bull menace (15.80%), reduction in muskmelon area (24.12%) and livelihood support (27.55%) on Dim-3 (Eigen value = 1.59, variance = 13.23%), and short crop duration (40.14%) and ease-in-management (17.44%) on Dim-4 (Eigen value = 1.13, variance = 9.38%) (Figure 4) (see detail in Online Supplementary Table S3).

4.4. Factors Affecting Muskmelon Conservation

The results of Tobid regression revealed that landholding size (-0.031, $p < 0.001$) and education level (-0.007, $p < 0.05$) had significant negative impacts on muskmelon conservation; every one unit increase in landholding and education would reduce muskmelon conservation by 3.10 and 0.70%, respectively. Conversely, muskmelon growers having two or more sources of income were likely to be better conservators; the increase in conservation being ~7% (Table 1). Likewise, an increase in market constraints from low to moderate would reduce muskmelon conservation by ~6%. Muskmelon conservation would decline by ~4.5% in the face of poor institutional support; for instance, lack of incentives for conservation and value-addition. Declining interest in farming would also adversely affect muskmelon conservation (~3.5%) in the foreseeable future as are the risks imposed by blue bulls and erratic rainfall (Table 1). Of the enabling factors, 'pleasant fruit taste' of the muskmelon landrace '*Jaunpuri Netted*' was found to have an overarching positive influence in sustaining its conservation (~10%). Cultural heritage (5.4%), livelihood support (4.5%) and social prestige (4%) were other prominent enablers crucial to muskmelon conservation in the study village (Table 1).

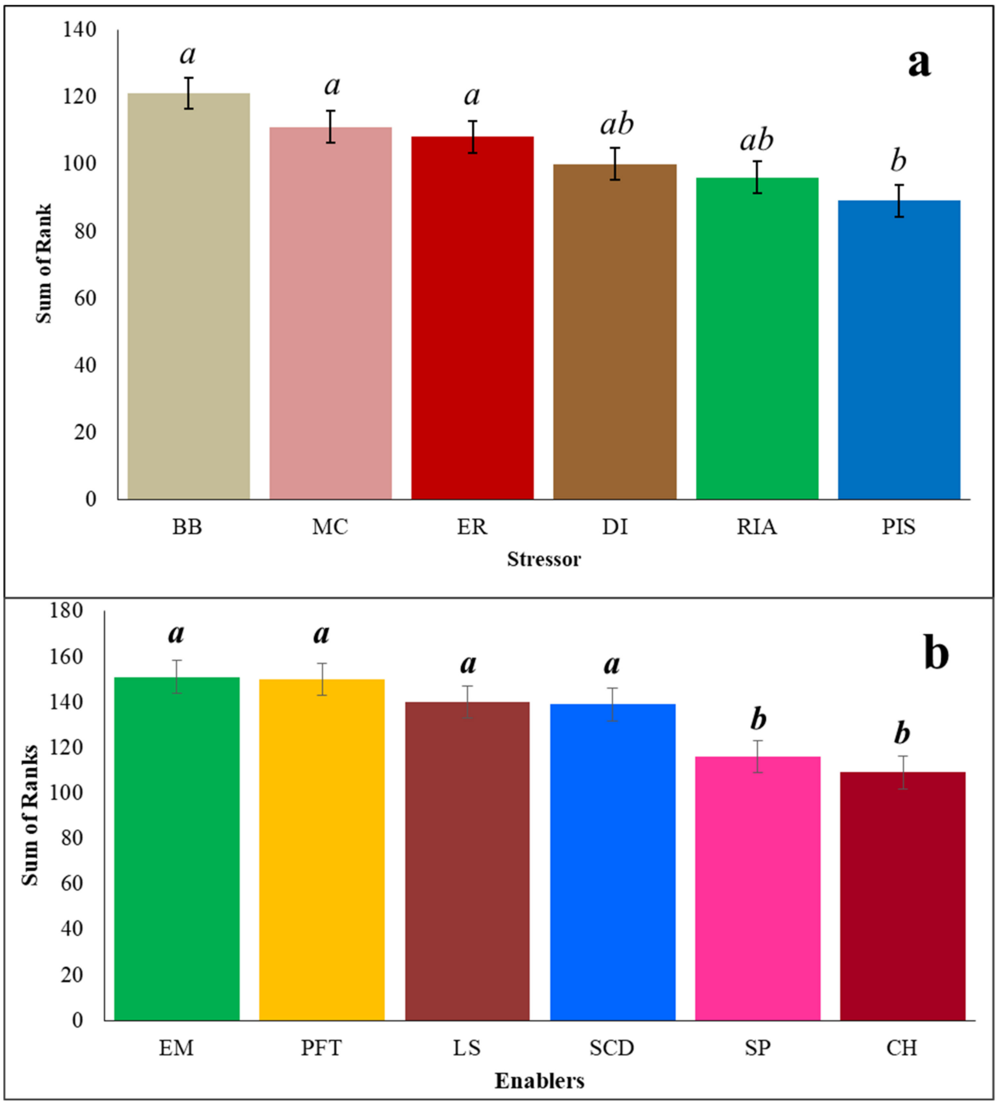

Figure 3. Test of significance of the mean ranks for stressors (**a**) and enablers (**b**). At least one common letter above each bar indicates non-significant differences ($p < 0.05$) as per Bonferroni–Dunn test. Abbreviations: BB—incidence of blue bulls, MC—market constraints, ER—erratic rainfall, DI—declining interest in farming including muskmelon cultivation, RIA—Reduction in area under muskmelon, PIS—poor institutional support; EM—ease-in-management, PFT—pleasant fruit taste, LS—livelihood support, SCD—short crop duration, SP—social prestige, CH—cultural heritage.

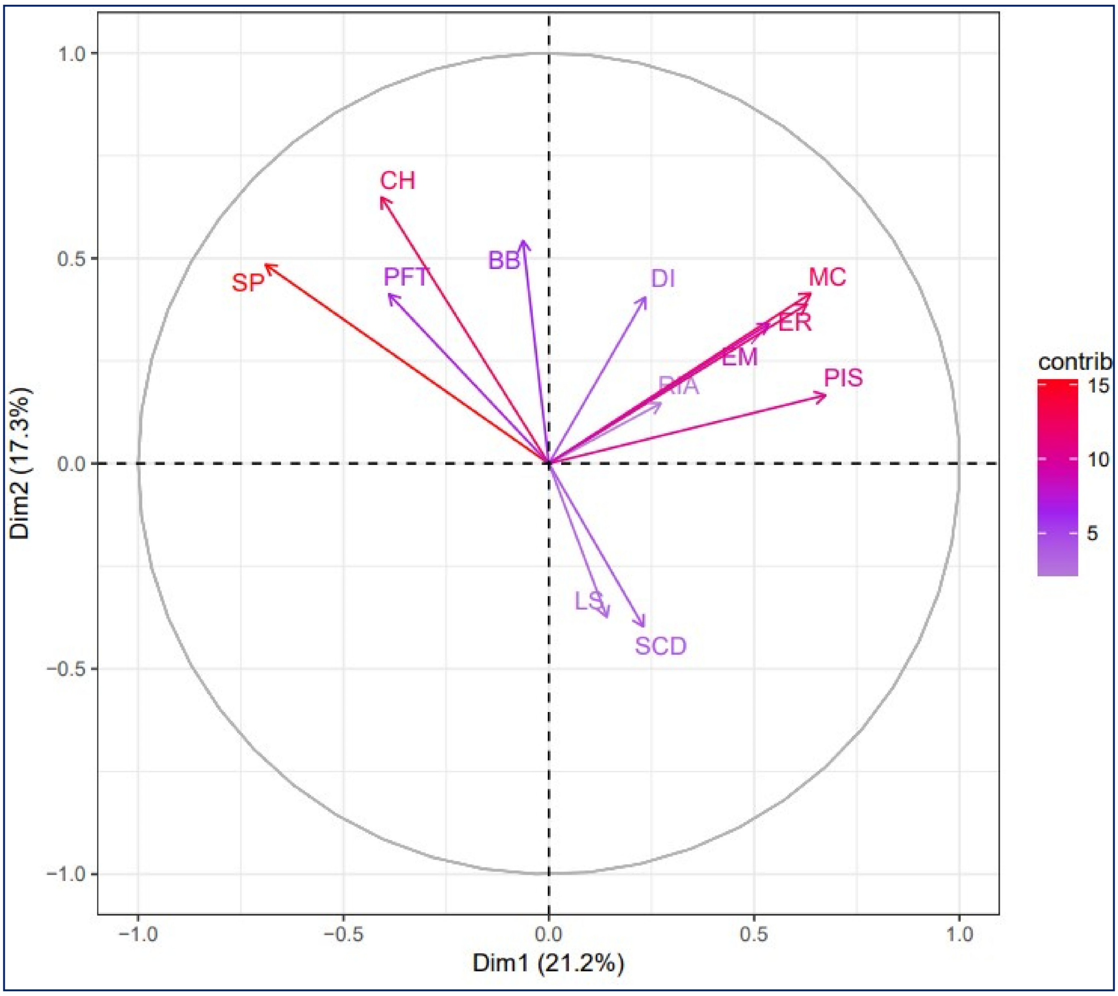

Figure 4. Principal Component Analysis biplot showing the loading of stressors and enables on the first two Principal Components. Abbreviations: BB—incidence of blue bulls, ER—erratic rainfall, DI—declining interest in farming including muskmelon cultivation, RIA—reduction in area under muskmelon, MC—market constraints, PIS—poor institutional support, CH—cultural heritage, SP—social prestige, SCD—short crop duration, EM—ease-in-management, PFT—pleasant fruit taste, LS—livelihood support.

Table 1. Tobit model estimates and the marginal effects showing positive and negative effects of different variables on conservation of muskmelon landrace '*Jaunpuri Netted*'.

Variable	Estimate	Standard Error	Marginal Effect	Standard Error
a. Socio-economic variables				
Intercept	0.238 ***	0.059		
Age	0.002 ***	0.001	0.002 ***	0.001
Experience	0.002 ***	0.001	0.002 **	0.001
Education	−0.007 **	0.003	−0.007 **	0.003
Total land-holding	−0.031 ***	0.010	−0.031 ***	0.010
Two sources of income	−0.017	0.014	−0.017	0.014
More than two sources of income	0.072 ***	0.020	0.072 ***	0.020
Extension contacts	0.041 **	0.019	0.041 **	0.019

Table 1. *Cont.*

Variable	Estimate	Standard Error	Marginal Effect	Standard Error
b. Perceived stressors				
Blue bull minace (high)	−0.026 *	0.015	−0.026 *	0.015
Erratic rainfall (moderate)	−0.028 **	0.013	−0.028	0.013
Erratic rainfall (high)	−0.006	0.023	−0.006	0.023
Declining interest (moderate)	0.035 ***	0.013	0.035 **	0.013
Declining interest (high)	0.014	0.021	0.014	0.021
Market constraints (moderate)	−0.060 ***	0.020	−0.060 ***	0.020
Market constraints (high)	−0.042 *	0.022	−0.042 *	0.022
Poor institutional support (moderate)	−0.046 ***	0.015	−0.046 ***	0.015
Poor institutional support (high)	−0.044 *	0.023	−0.044 *	0.023
c. Perceived enablers				
Cultural heritage (moderate)	−0.012	0.018	−0.012	0.018
Cultural heritage (high)	0.054 ***	0.018	0.054 ***	0.018
Social prestige (high)	0.040 ***	0.014	0.040 ***	0.014
Short duration (high)	−0.004	0.014	−0.004	0.014
Ease in crop management (high)	0.021 *	0.013	0.021	0.013
Pleasant fruit taste (moderate)	−0.005	0.020	−0.005	0.020
Pleasant fruit taste (high)	0.103 ***	0.032	0.103 ***	0.032
Livelihood support (moderate)	0.010	0.016	0.010	0.016
Livelihood support (high)	0.045 ***	0.017	0.045 **	0.017
Log Sigma	−3.333 ***	0.094		

Notes: Log likelihood of full model is 107.394 (df = 25) and Log likelihood of null model is −3.927 (df = 0), Chi-square statistics is 22.64 Pr (>is 0.000, leads to rejection of null hypothesis, suggesting that the full model offers a significantly better fit. *, ** and *** shows the level of significance of the variable at 10, 5 and 1% of the probability level, respectively.

4.5. Temporal Changes in Adaptive Management

We found that muskmelon crop management and traditional uses in the study village have undergone some drastic changes over the past few decades (Table 2). The study respondents were almost unanimous (94%) that greater use of tractor-drawn implements post-1991 has gradually led to little care in field preparation, and that obsession with higher fruit yields has considerably increased the use of market-purchased hybrid seeds. Traditionally, the fields were green manured using sun-hemp (*Crotalaria juncea* L.) and kept fallow until sowing. The night herding of sheep flocks during October-November was a common practice to further improve soil fertility. The fields plowed using the bullock-drawn *desi* plow (locally called '*hal*') were carefully leveled for creating a congenial tilth. Before sowing, the seeds would be soaked in water for 24–48 h, gently rubbed to remove the seed mucilage, mixed with ash and broadcast. About 88% of the respondents perceived that crop sowing has got delayed, largely due to growing interest in potato as a cash crop. The study farmers (91%) opined that increased chemical fertilizer use has taken a toll on organic practices for soil fertility management and that natural pesticides (e.g., *neem* cake) have largely been replaced by chemical pesticides. About 82% of the respondents informed that delayed harvesting of fruits has led to a perceptible reduction in farm profits, and that the traditional sale of seeds and seed oil extraction is no longer practised. Over time, there has been a surprising weakening of traditional social and family values with adverse implications for muskmelon conservation (Table 2).

Table 2. Temporal changes in the adaptive management practices for the muskmelon landrace '*Jaunpuri Netted*' [1].

Practice	Up to 1990	1991 to Present	Reason(s)
Field preparation	Use of *desi* plow, careful land levelling and pulverization	Tractor-drawn implements	Gradual replacement of indigenous tillage equipment
Seed source	Farmer-saved seeds	Farmer-saved and purchased (hybrid) seeds	Obsession with higher yields
Sowing time	mid-January to mid-February	Second week of February to first week of March	Potato cultivation
Fertility management	Fallowing, green manuring, sheep rearing, FYM and *neem* cake application	Increasing use chemical fertilizers	Crop intensification, diminishing availability of organic inputs
Plant protection	Application of *neem* cake	Pesticide sprays	Increased insect-pest infestations
Harvesting time	Last week of April to second week of May	Second to third week of May	Delayed crop sowing
Traditional uses	Use as dessert, gifting fruits to relatives, sale of fruits and seeds, seed oil extraction	Use as desert, sending to relatives and sale of fruits	Disappearance of seed chain, oilseed (e.g., mustard) cultivation
Indigenous institutions	Collective management (*sajha* system), resource pooling and exchange	Individual and independent approach	Disintegration of joint family system, erosion of traditional values and economic changes

Note: [1] This table was developed after focus group discussions held with key study farmers.

4.6. Reduction in Muskmelon Area

We noticed that area put under muskmelon crop has consistently declined over the past two decades. While relatively younger respondents (aged <60 year) perceived about a 25–30% reduction in area, relatively elder farmers (aged 65–75 year) estimated that total muskmelon acreage has reduced by about half compared to the 1980s. In order to have a reliable estimate, the temporal reductions in muskmelon crop area between 1992 and 2017 period were computed by acquiring and processing the satellite imageries from Landsat 5TM, 7 and 8 (Figure 5). The imageries for the peak period of fruiting (May) for the years 1992, 1997, 2002, 2007, 2013 and 2017 revealed that the total muskmelon area has decreased by ~43% in 2013 and by ~55% in 2017 compared to the base year of 1997 (see details in Online Supplementary Table S4).

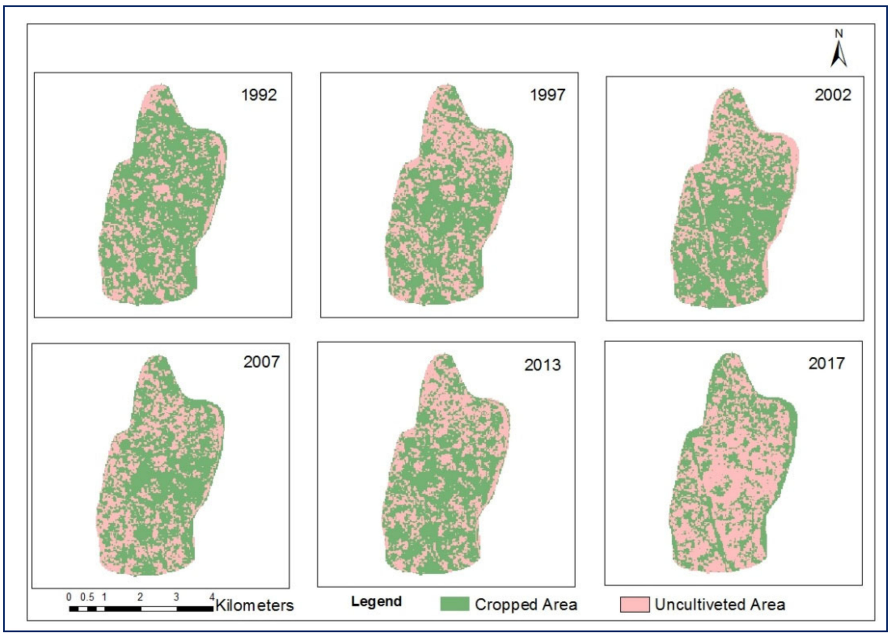

Figure 5. Temporal reduction in the total muskmelon area in the study village over 1992–2017.

5. Discussion

Global crop landrace diversity is vanishing at an accelerated pace [4], and this could have far-reaching impacts on social–ecological resilience and local livelihoods [15,16]; at least in marginal areas where resource-poor communities are still heavily dependent on local resources (e.g., agro-biodiversity) for their subsistence [25,58]. In this context, our study sought to identify the social, ecological, climatic and policy stresses posing risks to the sustained conservation of muskmelon landrace '*Jaunpuri Netted*' in Jaunpur district of Uttar Pradesh, India. We also delineated temporal changes in traditional practices relating to muskmelon conservation, and how this shaped farmers' adaptive practices to cope with the prevailing risks. Available evidence suggests that muskmelon cultivation in the study village (Jamaitha) commenced *c*. 1930 [34]. Although muskmelon is widely grown throughout the study district, any discussion on this crop will be incomplete without mentioning the study village (Jamaitha) [33]; reflecting an inseparable inter-generational human-plant relationship [59]. The study farmers' perceived that a pleasant fruit taste has been critical to the conservation of this landrace; better fruit quality and exquisite taste are the key reasons why farmers assign a greater importance to certain fruit and vegetable landraces over others [60–62]. Our finding that a sense of cultural heritage was one of the key enablers for the conservation of this landrace is corroborated by previous studies from India and elsewhere. Socio-cultural norms, religious values and cultural preferences all still play critical roles in the conservation of local agro-biodiversity [63–65]. A unique melon landrace that probably originated in the 19th century is still valued by the farmers in Villaconejos, Spain for its unique taste and sweetness [66].

We ultimately found that some social–ecological and policy stressors are increasingly posing serious risks to the muskmelon-based livelihoods in the study village (Figure 6). For instance, the past few decades have witnessed an unprecedented increase in blue bull and stray animal populations; causing heavy damage to the muskmelon crop and often compelling the growers to fence their fields using bamboo poles and barbed wire. Blue bull, the largest Asian antelope, is a major threat to crop production in northern India [67]. As the study village (Jamaitha) lies on the bank of the Gomti River, blue bulls take shelter in the river vegetation during day hours and damage muskmelon and other crops during the night [68]. Based on insights from other crops, the use of dung/neem sprays, placing effigies in the fields, and provision of guard dogs could be some feasible remedial measures to addressing the blue bull menace [67]. Our study respondents were almost unanimous (92.5%) that changing climatic conditions in general and erratic rainfall, in particular, were increasingly causing considerable damage to muskmelon crop: erratic rainfall had frequently caused moderate damage over the past 10–15 years. Notably, a majority of the study farmers (63%) opined that timely (early) sowing—though mostly not in practice—may give some respite from erratic rainfall: it ensures a vigorous crop somewhat resilient to weather anomalies. In northern India, cucurbits including muskmelons are mostly grown on riverbeds for harvesting in early summers [69]; muskmelon fruits often attain a premium quality under warm, dry and sunny conditions [28]. Damage caused by erratic rainfall can be alleviated to a great extent by aligning the sowing date with indigenous practices of rainfall prediction [70], and by adopting the affordable low-tunnel protected cultivation technology [69]. The study farmers' perception that alienation of village youth from farming would adversely affect muskmelon conservation in the foreseeable future is also supported by studies from India and elsewhere [71–73]. The income differences between farm and non-farm occupations often compel the rural youth to severe their links from farming [71]; this 'generation problem' across the globe highlights the need for linking the educational processes with technology- and skill-driven agricultural development compatible with the principles of sustainability, agro-ecology and food sovereignty [73]. Muskmelon growers (~76%) lamented that weak marketing linkages continue to slash their profits to a considerable extent; they informed that in contrast to the earlier practice of selling the fruits on the city market (Jaunpur district headquarters), fruits are being largely sold on the local village market for about last 10 years; this may partly explain reduced profits as muskmelon farmers are mostly compelled to sale the fruits on local village market on terms and conditions set by the intermediaries [33].

In spite of aforementioned stressors, a majority of the village farmers were not in favour of abandoning the muskmelon cultivation in the near future; a set of enabling factors keep them engaged in muskmelon farming (Figure 6). As mentioned previously, for most study respondents, muskmelon cultivation was a matter of social prestige and a cultural legacy inherited from their forebears [74]; this, together with relative ease in crop management [69], pleasant fruit taste [61], perceived livelihood support [1], and short crop duration [69], account for the continued interest of the study farmers in muskmelon cultivation. Our findings revealed marked temporal changes to the traditional ways in which muskmelon crop has been managed and used over the past two-three decades. It emerged that indigenous bullock-drawn implements have largely been replaced by tractor-drawn implements, and this has gradually made the local soils more compact, erosion-susceptible and less favourable to muskmelon crop [75]. Likewise, a growing obsession with higher fruit yields has led to the increased use of market-purchased hybrid seeds; a trend also reported from other parts of the world [66]. Muskmelon landraces in Indian states like Uttar Pradesh (*Lucknow Safeda*, *Baghpat*, *Jaunpuri Netted and Kajari*), Punjab (*Haridhari*), Rajasthan (*Tonk*), Madhya Pradesh (*Kharri*), Maharashtra (*Goose* and *Kavit Jam*) and Andhra Pradesh (*Bathesa*) are mostly grown using the farmer-saved seeds [32]. Of late, however, market-purchased hybrid seeds are increasingly being used for higher yields; for instance, in some parts of Uttar Pradesh (study state) [76,77]; landraces and modern cultivars/hybrids play overlapping roles in farmers' livelihoods and their extent of adoption is often governed by production and consumption decisions, cultural preferences, and market conditions [65].

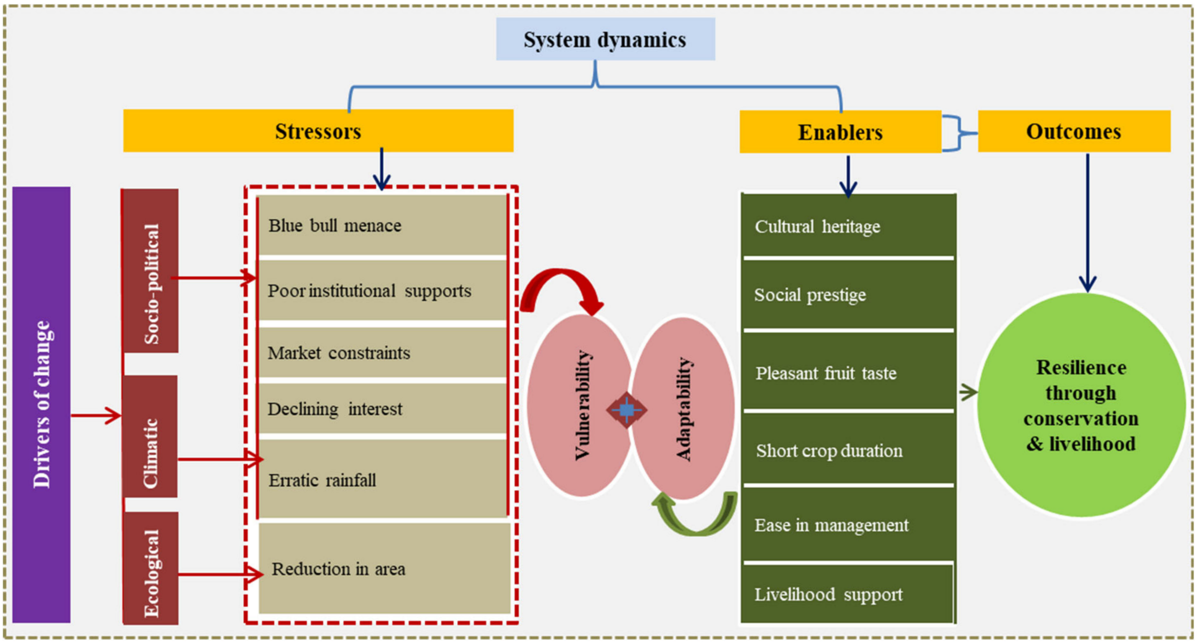

Figure 6. The empirical framework of the study showing interplay between stressors and enablers in relation to the conservation of and livelihood opportunities from muskmelon landrace '*Jaunpuri Netted*'.

The traditional practice of night herding of sheep flocks in muskmelon and other crop fields (termed penning) has virtually ceased to exist. Penning is considered to be effective in improving soil fertility enhancement and in suppressing weed growth. Crops in the penned fields are usually vigorous, more productive and of a better quality than those in the non-penned fields [78]. A majority of the study farmers said that potato cultivation, in general, tends to delay the muskmelon sowing; in some years even up to the first week of March, causing appreciable reductions in fruit yield, quality and the farmers' incomes.

Generally, the early (January) sowing results in better crop growth and the fruits attain saleable maturity as early as the second week of May while the February sown crop is usually ready in the last week of May when the market is already glutted with muskmelons. Delayed sowing of muskmelon (last week of February through March) has also become quite common in other areas of the study state (Uttar Pradesh) where potato and mustard are grown as cash crops [79]. Commercial potato cultivation has completely eclipsed several traditional crops in the Central Himalayan region of India [19]. A major finding of this study was that the traditional sale of muskmelon seed and seed oil extraction for household consumption are no longer in practice. Muskmelon seeds, generally discarded as a waste, hold enormous economic potential for use as ingredients in novel functional foods [80], and for extracting the muskmelon oil for reducing the dependence on other vegetable oils used in biodiesel production [30]. In some parts of Uttar Pradesh, muskmelon is exclusively grown for seed production. Farmers specializing in the seed crop do not sell the fruits. Instead, the fruits are consumed by the farm households themselves and the seeds collected for sale [79].

Over time, there has been a surprising weakening of traditional social and family values with adverse implications for muskmelon conservation. Globally, it has been recognized that erosion in traditional cultures, and changes in socioeconomic spheres, especially among the younger generations, may accelerate the depletion of local agro-biodiversity [81]. The diversity in traditional practices of small farmers and marginalized communities has played a pivotal role in sustaining biocultural diversity [82]. The erosion of such resources and the associated knowledge and institutions ascribed to factors such as ecological stresses (e.g., blue-bull menace in the present case), may result in severe impairments in the ecosystem services and functions [83]. Naturally, such stresses are often detrimental to the farmers′ adaptive capacity, such that sustainable biodiversity conservation and the traditional knowledge systems are heavily jeopardized [84]. Such issues need to be implemented in a systematic way by re-framing institutional designs [84,85]; this state of affairs also highlights the need for integrating modern crop husbandry practices (science), and the institutional support with traditional practices and values for sustainable agro-ecosystem management [86,87]. Linking local knowledge and socio-cultural values with relevant cross-sectorial developmental programs and policies, and incentive mechanisms is critically important to protecting local agro-biodiversity [83,87]; this, when implemented via a stakeholder approach, can substantially contribute to conserving the agro-biodiversity while also contributing to achieving some of the targets under Sustainable Development Goals (SDGs) and other global environmental polices (e.g., Aichi Biodiversity Targets and Land Degradation Neutrality) [88,89].

6. Conclusions and Policy Implications

Agriculture in India, similar to other parts of the world, has witnessed several profound changes over the past few decades. Increased adoption of modern technologies and high-yielding cultivars has gradually pushed traditional crops and landraces, and the associated traditional knowledge to the margins. Crop landraces contribute enormously to building and maintaining social–ecological resilience; especially in marginal areas where local communities are still heavily dependent on natural resources and traditional knowledge for sustenance. Available evidence suggests that crop landraces, better adapted to low-input and sub-optimal conditions than modern cultivars, have a remarkable potential to addressing food insecurity and malnutrition concerns in areas grappling with social-policy stressors and climate change impacts. Our findings suggested that conservation of muskmelon landrace '*Jaunpuri Netted*', a long-cherished cultural legacy valued for its exquisite fruit quality, is threatened by a suit of social–ecological, policy and climatic stresses; these stresses alongside declining interest in farming and the poor institutional support have led to a surprising reduction in area devoted to muskmelon crop over decades, and most traditional practices relating to its conservation have virtually vanished. Although we do not wish to paint a gloomy picture, the situation is slowly approaching the tipping point and the fateful loss of this landrace remains imminent. We argue that adequate research and policy support remain absolutely essential to reviving the local farmers' enthusiasm in muskmelon conservation. A significant policy implication of our study is that the blue-bull menace can partly be managed by community-scale farm fencing and management by the pooled use of resources.

As socio-economic variables, farmers′ perception, stressors and market constraints all adversely impact muskmelon conservation, a stakeholder approach involving the farmers, researchers, extension functionaries, state developmental agencies and the consumers is needed to adapt to the prevailing risks. The unique food, nutraceutical and industrial values of this landrace vis-à-vis modern muskmelon cultivars need to be investigated to convince the policy makers for its sustained conservation. Adequate emphasis is also needed for restoring the traditional practices to partly slash the production costs and improve profits. There is also the need for achieving the synergy between scientific knowledge and the traditional practices of muskmelon crop management. Establishing small-scale grading and packaging units, each consisting of a few households, can further increase the profits from the muskmelon crop. There is a scope for mainstreaming this traditional crop with some relevant policies, e.g., 'One District One Product' with the overall aim of branding it at the regional and national levels, as this may further strengthen the conservation efforts. Last but not the least, the custodian farmers need to be sensitized that their efforts in conserving this muskmelon landrace could also contribute immensely to some of the Sustainable Development Goals viz. 'Good Health and Well-being', 'Decent Work and Economic Growth', and 'Sustainable Cities and Communities'.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su14169880/s1, Table S1: Measurement of the socio-economic profile of the muskmelon growers; Table S2: Frequency distribution of stressors and enablers; Table S3: PCA analysis of variables and their contribution (%); and Table S4: Analysis of temporal changes in muskmelon crop area.

Author Contributions: Conceptualization, A.S. and R.K.S.; Data curation, A.S., R.K.S. and N.K.; Formal analysis, A.S., R.K.S. and S.K. (Suresh Kumar); Investigation, A.S.; Software, N.K.; Supervision, P.C.S.; Writing—original draft, P.S., D.S. and S.K. (Satyendra Kumar); Writing—review and editing, A.S. and R.K.S. All authors have read and agreed to the published version of the manuscript.

Funding: This study was financially supported under the Lal Bahadur Shastri Award Project (NRMACSSRISOL 201601600914) of the Indian Council of Agricultural Research, New Delhi.

Informed Consent Statement: Farmers were explained about aim of study and its probable outcomes; they wished to remain anonymous except the disclosure of geographical identification. All the study farmers provided their free and inclusive informed consent for this research to record their data and published it digitally and in hard copy forms. The study was approved (Reference No. 25-2022) by the Priority, Monitoring and Evaluation Cell, headed by Director of ICAR-Central Soil Salinity Research Institute, Karnal, Haryana, India. Ethical review and approval does not apply in this study as humans or animals were not the direct subject of treatments.

Data Availability Statement: Sufficient data provided in article and in form of online resources.

Acknowledgments: We thank muskmelon growers and the key respondents for sharing their knowledge and practices with us. Pranvijay Singh (Jamaitha, Jaunpur) and Nitesh Singh (Banki, Jaunpur) are wholeheartedly thanked for their support during rapport building and data collection. ICAR-CSSRI, Karnal is acknowledged for logistic support. Officials of District Agriculture Department and Krishi Vigyan Kendra, Jaunpur are appreciated for their help. The comments and suggestions received from four anonymous reviewers, that have improved the quality of the paper, are also thankfully acknowledged.

Conflicts of Interest: The authors declare no conflict of interest.

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