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Gender, social, household, and ecological factors influencing wheat trait preferences among the women and men farmers in India

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The goal of public breeding programs is to develop and disseminate improved varieties to farmers. This strategy aims at providing farming communities with superior crop varieties than they are growing. However, the strategy rarely considers the needs and preferences of farmers, especially gendered preferences, failing to solve real field problems by addressing the differences and inequalities prevalent in the farming communities. Our research examines how personal, household, agronomic and ecological characteristics of wheat growers in Bihar, India's eastern Indo-Gangetic Plains, affect women and men's wheat trait choices. Data were obtained from 1,003 households where both male and female respondents from the same household were interviewed. We accounted for 23 traits of wheat from a careful assessment of production, environment, cooking quality, market demand, and esthetic criteria. Binomial logistic regression was used to determine women's and men's trait preferences. The results imply that gender influences the preferences of wheat traits. Some traits are favored by both women and men, however, in other instances, there are striking disparities. For example, men choose wheat varieties that are well adapted to extreme climate conditions, have a higher grain yield, and produce chapati with a superior taste, while women prefer wheat types with superior chapati making quality, higher grain yield, and high market prices. Other socioeconomic, agronomic, cultural, and geolocational factors have a considerable impact on trait preferences. These human dimensions of traits preferred by women and men farmers are important for trait combinations to develop breeding product profiles for certain market segments.

KEYWORDS

wheat traits, gender, trait preferences, logistic regression, Bihar

1 Introduction

Public breeding programs traditionally follow a supply-driven approach, which attempts to develop and disseminate improved varieties that meet or outperform the predefined trait criteria set by the governmental agencies and are expected to enhance grain yield, disease resistance, climate resilience and market acceptability. Although this approach has a good

intention of providing the best crop varieties to farmers, it often fails to consider their needs and preferences. There is almost non-existence of a mechanism that connects the farmers' needs and preferences with the breeders' product profiles (Suri and Gartaula, 2023). Product profiles are the set of targeted attributes that a new crop variety or animal breed is expected to meet to successfully be released onto a market segment (Ashby and Polar, 2021), which is a geographic area or a group of people having a relatively homogeneous demand for a crop variety or a commodity in general (Ragot et al., 2018). Consequently, hundreds of improved crop varieties never reach the farmers' fields or have limited adoption, making the traditional public breeding program a place for academic exercise, rather than providing solutions to the real field problems, especially in the Global South, including India. This has resulted in a slow turnover of improved varieties, especially among the resource-poor and marginalized farmers who continue cultivating old varieties that are susceptible to pests and climatic stresses (Krishna et al., 2016).

In recent years, borrowing the approach from the private sector that have been applying it for a longer time, public sector breeding has started collecting farmers' demands and requirements to feed into their breeding pipelines and developing target product profiles (Teeken et al., 2021). This brings down to the understanding of the needs and preferences of diverse end-users, including women, men, the poor and other marginal farmers, and feeding them into the breeding pipeline, an approach called demand-led breeding (DLB, 2022). Moreover, in addition to considering biophysical and climatic parameters, mobilizing market intelligence to understand the end-user perspective is equally important to develop better market segmentation and breeding product profiles (CGIAR-EiB Platform, 2019). This will help improve crop varieties to address problems associated with biophysical, social, economic, and climatic challenges farmers are facing, which eventually lead to better adoption, faster turnover, and deliver improved genetic gains to the farmers' field. In this paper, we examine how the personal, household, agronomic and ecological characteristics of the wheat growers in Bihar influence wheat trait preferences among women and men farmers.

Wheat makes a good case for studying trait preferences in India, not only because it is the major cereal crop cultivated in about 30 million hectares of agricultural land and a critical commodity for the farmers' livelihood system, but also because India is the second-largest wheat-producing country in the world after China, contributing to the food security and economy of the country and at the global scale (Joshi et al., 2007; Tiwari et al., 2014). The history of wheat improvement in India dates to 1960s, the Green Revolution era, when the high-yielding semi-dwarf varieties were introduced and since then several improved varieties have been released in the country (Gupta et al., 2018). Wheat improvement is mainly done through the government funded program under the All India Coordinated Research Project on Wheat and Barley, nationally coordinated by the Indian Institute of Wheat and Barley Research (IIWBR), a subsidiary of the Indian Council of Agricultural Research (ICAR).

Wheat yield in Indian states varies according to the technology used and agroclimatic conditions (Soni et al., 2017), with a productivity gap of more than 40% in the eastern Indo-Gangetic Plains compared to the west (Badstue et al., 2022). The growing popularity of high-yielding varieties and mechanization have increased the demand and wages for male labor but decreased the same for female labor due to limited scope for performing women's traditional tasks of transplanting and weeding in mechanized wheat production system (D'Agostino, 2017). This further marginalized women in the wheat sector in terms of their wages and agency in decision making, despite their significant presence in the provision of labor (Farnworth et al., 2023).

New varieties could be developed to address various concerns and these technologies (new varieties) could be transferred to farmers' fields (Joshi et al., 2007; Soni et al., 2017). Due to smaller landholding and staple diet of people, wheat is cultivated almost exclusively for subsistence and fulfilling the dietary requirement of the household members, indicating an important (reproductive and economic) role of women farmers, and justifying the importance of gender consideration for wheat varietal selection and trait preferences in Bihar (Badstue et al., 2017). However, to what extent do the existing (public) breeding programs consider the inputs from diverse groups of farmers, including women, the poor and marginalized, in a participatory manner? Suri and Gartaula (2023), in a recent study conducted in the same region, report a lack of a feedback mechanism to collect farmers' needs and experiences. They observed that some meetings and workshops organized at regional levels are represented by the so-called progressive farmers, who are mainly men or rich, limiting the opportunities for women and marginalized farmers to provide input.

The way women and men farmers are considered in the process of target product profile development also depend on how gender and other intersectional factors are organized in a society. Generally, in India, and particularly in Bihar, caste system has a strong influence on how household decisions are made and how women are involved. Caste in Hindu society is a hierarchical system marked by superiority and purity beliefs. At the top are the General Caste (GC), so called upper caste, followed by mid-level Other Backward Castes (OBC) and marginalized groups like the Scheduled Castes (SC, Dalits) or the lower caste and Indigenous people or the tribal communities (Adivasi, Scheduled Tribes or ST) with different levels of men and women's involvement in access to resources and household decision making (Bidner and Eswaran, 2015). Moreover, the intersectional identities of gender, caste, and class are attuned to create opportunity structures that may make certain groups privileged, while others deprived of accessing resources, services, and livelihood options (Patnaik and Jha, 2020; Farnworth et al., 2023). For example, women in upper caste and women in lower caste households, or in poor or rich households are not the same, and they have different access to information and decision-making over varietal selection.

As such, to promote farmers' meaningful participation in varietal development, agronomists, plant breeders, and policymakers must understand the preferences and needs of the farming community. This would not only aid in the promotion (or introduction) of new varieties but also in their wider scaling (Krishna and Veettil, 2022). Perhaps due to not having a robust feedback mechanism on how farmers could feed their needs and preferences into breeding pipelines with their diverse and context-specific needs, breeders continue to work on the predefined traits, such as yield and tolerance to biotic and abiotic stresses, with relatively less tailored to the needs of the farmers' specific contexts. To address these context-specific needs and preferences and develop more targeted product profiles, modern breeding programs are trying to step up from the conventional approach and striving to go beyond productivity and economic gains and the biotic and abiotic traits to feed into the breeding pipelines. As such, non-biophysical

traits such as milling, baking, and cooking quality have long been considered for wheat breeding programs (Nehe et al., 2019).

The preference to choose certain traits may differ depending on the ecological, social, economic, and cultural contexts of farmers, the ultimate adopter of improved varieties. However, the existing literature lacks these dynamic realities of the farming contexts. Earlier studies have focused on grain yield, compared to a negligible focus on other traits such as straw yield, height, grain size, tillering, seed rate, climate stress, disease resistance, crop duration, and market demand. There are also negligible enquiries into traits such as biofortified wheat, chapati making quality, threshability, and processing quality of wheat grain. Gender and social differentiation were also inadequately considered in many of these studies. Therefore, in our study, we have considered 23 traits related to the climatic, agronomic, genetic, economic, and esthetic characteristics of wheat. We have not found any previous study that has considered these many traits in a single analysis.

It is often assumed that women and men have different trait preferences, but very few studies have performed a systematic analysis on how gender of a farmer plays a role in trait preferences. The comparison between male vs. female household heads is the classic gender comparison; however, gender analysis goes beyond the household headship and affected by several intersectional factors of age, caste, class, and geographies. For example, Krishna and Veettil (2022) indicate that women and marginalized farmers in India preferred better grain quality (for the chapati making) of wheat, compared to yield-enhancing and risk-ameliorating traits. Tesfaye et al. (2020) observed that yellow rust resistance, frost resistance, grain yield, and white grain color are among the traits that Ethiopian wheat farmers (no gender and social segregation) preferred the most. By doing a sex-disaggregated analysis, Gartaula et al. (2024) observed that women prefer traits that give good taste and have better cooking quality, while men preferred high biomass and resistance to diseases, among Ethiopian wheat growers. In contrast to these straightforward trait preferences, Teeken et al. (2021) made a different observation in their cassava study in Nigeria and reported that trait preferences are complex and go beyond men's traits versus women's traits. They observed significant differences in prioritization between women and men of different cassava trait preferences. They further illustrated regional differences as an important factor where the cultural use of cassava is different, and poverty and food security of farm households are among other crucial factors. Using the case of rice, Bacud et al. (2024) demonstrate how diversity of marginalization and intersectionality matters more than men vs. women's traits. They observed that the intersection between gender and other socioeconomic categories like sex of the household head, lower-and upper-income groups provides varied response to women's and men's trait preferences.

As such, the contemporary literature on wheat trait preferences and crop improvement does not pay enough attention to the heterogeneity of farmers caused by gender, social, economic, and other household characteristics, as most of these studies consider farmers a homogeneous category. This paper will shed light on how trait preferences interact with the female and male farmers' personal, household, agronomic, and ecological characteristics. This characterization of the influencing factors in the wheat trait preferences among women and men farmers will help analyze our results (partially) using the socio-ecological systems model. This model helps us to understand the social prescriptions and expectations of the roles of women and men farmers, and gender-based values, beliefs, and practices in agriculture-based livelihood systems (Oteros-Rozas et al., 2019; UNFPA, 2019). Using this model, we illustrate how gendered wheat preferences are influenced by individual/personal, household, agronomic (technical), and ecological contexts, and we will further discuss the relevance of policy and the wider contribution to the literature. To perform this highly interdisciplinary socio-ecological analysis, we will seek answers to the research questions: How do male and female farmers differentiate the wheat varietal trait preferences? How do trait preferences interact with gender, socioeconomic, household, agronomic, and ecological characteristics of farmers and farm households? And, what lessons could be learnt for crop improvement through gender-responsive trait prioritization and associated breeding product profiles?

2 Methodology

2.1 Research design, data collection and analysis

This study is designed to analyze socially disaggregated information based on gender and other social identities such as age, education, caste, and ethnicity. We understand that the decision-making in agricultural innovations happens inside the household, and thus considering head of the household as the gender parameter could be misleading by not capturing the intra-household gender dynamics (Shibata et al., 2020). Therefore, we collected data from female and male respondents from the sample households. This yielded a total of 1,003 households, including men (1,003) and women (1,001) primary decision makers (ideally the spouses, and in this paper referred to as primary man and primary woman) from the same households for allowing their own perspectives rather than the household as a single unit. In one household, respondents who declined to be interviewed separately (independent of each other or without influencing each other's interviews) were discarded from the analysis. The sampling frame was prepared based on the village census carried out earlier by CIMMYT for another study, covering the four agroecological zones in the Bihar State of India. To have more distributed sampling across the state, we followed a stepwise stratified random sampling: first, randomly selected 10 (out of 38) districts, and four villages in each district, and finally about 48–54 women and men respondents were selected for interviews from each village.

In this paper, we included 23 traits and characteristics of wheat, identified through a rigorous review of the literature, and based on the experiences of wheat breeders working in CIMMYT. These traits were related to production, climate, cooking attributes, market demand, and other esthetic values such as color, flavor, etc. (Table 1). As trait preference was measured on a binary scale ("yes" =1 and "no" =0), we used binomial logistic regression to identify factors associated with men's and women's trait preferences. The 15 independent variables used in the regression analysis and their expected relationship with the preference for wheat traits are provided in Table 1.

The age of the respondent (AGE) is a proxy for the duration of experience of the respondent working in the agricultural sector, which may affect their decision to have preference over certain traits. We hypothesize that older people may be more inclined to yield-enhancing traits than younger people. Education, which means the

TABLE 1 Independent variables and their expected hypothesis.

Covariate	Notation	Explanation
Age	AGE	Age of the principal man and woman. Older respondents prefer certain traits that are more of economic value, whereas younger one go for climate resilient.
Education	EDU	Education of the principal men and women, in years of formal schooling. Well educated respondent prefers yield enhancing and climate resilient traits.
Marriage status	MARRY	Marital status of the respondents. Respondents who are living with spouses prefer certain traits.
Household head	HEAD	Respondent is the household head. When the respondent is household head, he/she take part in household decision-making and prefer certain type of traits. Involvement in decision-making on wheat farming increases preference for the traits.
Caste group	CASTE	Caste also determines the preference of wheat traits. Disadvantages and backward caste prefer yield enhancing traits.
Religion	RELIGION	Religion and diets are related thus may influence wheat trait preference.
Wheat cultivated area (acre)	AREA	Wheat cultivated area, measured in acre. Higher the area, more preference on the yield and market demand traits.
Cultivated at least one new wheat variety over the last 5-year period	NEWVAR	New wheat variety introduction in recent years demand yield enhancing wheat traits.
Summative index for the 26 wheat production constraints	WPCONS	Sum of 26 self-reported wheat production constraints, measured as presence (1) and absence (0). Higher number of wheat farming constraints positively relate to trait preference. Higher the constraints, higher will be the preference.
Summative index for the 12 household amenities	ASSET	Sum of the 12 household amenities, measured by presence (1) and absence (0). Higher number indicates well-off family and may demand certain traits.
Ate less food than thought over 12 months	LESSFOOD	Insufficient food at household means more demand of wheat traits.
Water logging problem in any area of the land	WRLOG	Self-reported water logging problem in the agricultural plot, measured as 1 when yes, and 0 otherwise. Water logging problem may determine certain wheat traits, for example short height, logging resistance and so on.
Soil salinity problem in any area of the land	SOILSAL	Self-reported soil salinity problem of the agricultural plot, measured as 1 when yes, and 0 otherwise. Soil salinity may affect preference of wheat traits.
Flood hazard category	HAZARD	Flood hazard categories of the district. Intensity of flood hazard may determine the preference of certain traits, for example logging resistance in the case of high hazard areas.
Agro-climatic zone	AGROZONE	Agroecological zonation of the district.

number of years of schooling (EDU), may enhance preferences on wheat traits, so we assume a positive relationship of EDU with all traits. Other independent variables included in the regression are the marital status of the respondent (MARRY), household headship, whether the respondent is the head of the household (HEAD), caste group, whether the respondent self-identifies as scheduled caste, other backward castes, or a general caste group member (CASTE), whether the respondent identifies as a Hindu or Muslim (RELIGION), wheat acreage (AREA), whether the respondent has cultivated at least one new wheat variety in the past 5 years (NEWVAR), number of production constraints selected by the respondents (WPCONS), household assets (ASSET), whether the respondent ate less food over the period of last 12 months (LESSFOOD), whether the respondent reports waterlogging (WRLOG) or soil salinity (SOILSAL) problems in any of their cultivated plots. To give an ecological perspective in the analysis, we included two variables: flood hazard category (HAZARD) and agroclimatic zone (AGROZONE) of the districts. Flood hazard categories (high to very high, moderate, and low to very low) were derived from a government report (NRSC-ISRO, 2016) and four agroclimatic zones (zones I, II, IIIa, and IIIb) from a website (Thakur, 2020).

The 15 independent variables were then classified into four groups: personal, household, agronomic, and ecological characteristics. Variables in personal characteristics include age, education, marital status, and household headship, while household characteristics include caste group, religion, introduction of new wheat varieties, household assets and perceived food security. Likewise, the agronomic characteristics include the area under wheat cultivation, the number of wheat production constraints reported, and the waterlogging and soil salinity conditions reported, and the ecological characteristics are the hazard categories and agroclimatic zones.

2.2 Characteristics of research location

The study draws on data collected from 10 districts of Bihar, India, covering all four agroecological zones of the state: Zone I – North-west alluvial plain, Zone II—North-east alluvial plain, Zone IIIa—South-East alluvial plain and Zone IIIb—South-West alluvial plain (Figure 1). Zones I and II are located north of the river Ganges, while the other two zones are located south, placing the whole state on the river

FIGURE 1
Map of Bihar showing the study districts and sample villages (shown as triangles) by agro-climatic zones. Source: Village coordinates extracted from Google Maps by authors.

floodplain. Located in the eastern Indo-Gangetic Plains, Bihar is the second most populated (over 104 million) state in India after Uttar Pradesh. It is one of the poorest states, with about 52% of the population living below the poverty line. Caste wise, the Extremely Backward Classes (EBC) dominate with 36% population, followed by OBC (27%), SC (20%), ST (2%), and others. Religion wise, it is predominantly occupied by Hindu (83%) and Muslim (17%) followers with negligible presence of others (NITI Aayog, 2021); approximately 90% of the population lives in rural areas and more than 80% practice agriculture as a source of income in an average landholding size of about 0.4 ha, much less than the national average of 1.15 ha (Keil et al., 2019). Bihar's agriculture is characterized by smallholding, rice-wheat dominated cropping system, with many non-and off-farm economic activities built into the livelihood system where women and men household members put their efforts to strive for a living. About 74% of the state workforce is employed in agriculture and related sectors, which contributes about 20% to the state economy (Thakur, 2020). Another important consideration in Bihar is the widespread inequalities caused by age, gender, class, caste, and ethnicity (Badstue et al., 2022), which implies the agency of women and men farmers in selecting suitable crop varieties according to their livelihood requirements.

3 Results

The women and men farmers mentioned that they cultivate different wheat varieties on their farmlands. They have used both private (Shriram 303, Kedar Ankur, etc.) and public sector (UP 262, HD 2967, etc.) varieties, with the dominance of Shriram 303, UP 262, and HD 2967 as the top three most preferred varieties. They have been cultivating very old varieties (released in 1978) to recently released varieties like HD 3226 (released in 2019). These varieties have different attributes and characteristics, abiotic, biotic, and esthetic (Figure 2). Shriram 303 has been the most popular variety, covering more than 40% of the total area where farmers grow wheat. Farmers could not identify some varieties they have cultivated on their farmlands.

3.1 Does gender matter in wheat trait preferences?

The results indicate that gender does matter in trait preferences. Some traits are preferred by both men and women, while in some cases there are marked differences. As presented in Figure 3, men prefer the wheat varieties that are well adapted to extreme climatic conditions, and had superior chapati taste, while women prefer wheat varieties with better quality for chapati making (dough extensibility) and high market values; higher grain yield is preferred by both women and men. Few traits are preferred by more than 50% of the respondents and, except for the 'red color' trait, all other preferences are statistically significant at the 5% level on the Chi-square test.

We have aligned these differences in trait preferences between women and men farmers (Figure 4), showing that traits related to climate resilience, grain yield, chapati taste, grain size, tillering, market demand, straw yield, grain processing quality, threshability, and disease resistance are among the top 10 traits preferred by men, while chapati taste, grain yield, market demand, grain size, tillering, grain processing quality, chapati making quality, disease resistance, lodging tolerance, and climate-smart are among the top 10 traits

FIGURE 2
Wheat varieties used by the respondent farmers with released year and main attributes.

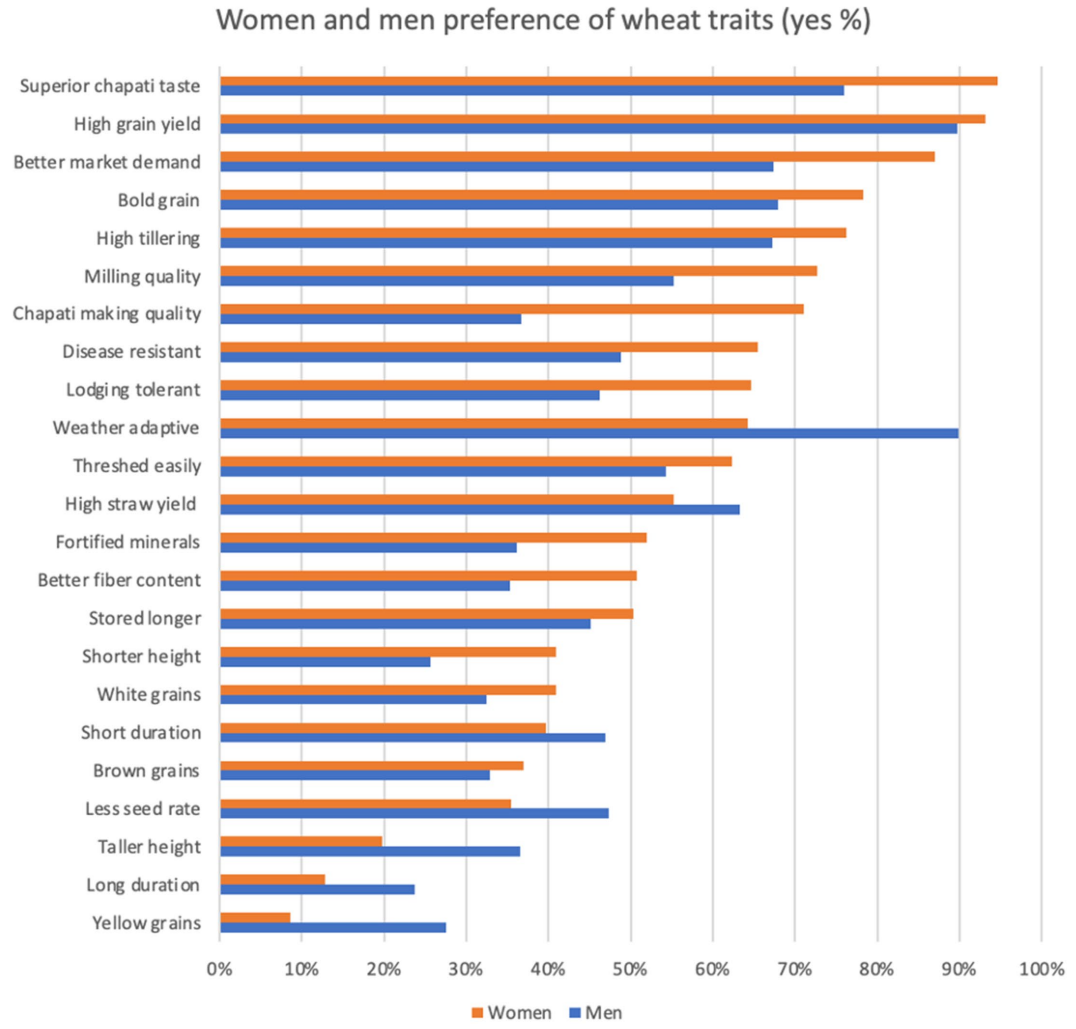

FIGURE 3
Wheat trait preferences for women and men (Yes %).

preferred by women, both in the order of high to low preference in ranking. Looking closely, threshability and straw yield are among the top 10 men traits that are not part of the women's list, whereas chapati making quality in grain and lodging tolerance do not make it to the men's top 10 list. The other eight traits are the same for both women and men, with some differences in priority sequence. These observations indicate that the traits of economic importance and productivity are among the most preferred wheat traits for both women and men, but women go a step further to include the taste and esthetic value of the grain in the list.

3.2 What factors influence wheat trait preferences?

The summary statistics of the independent variables used in the logistic regression are presented in Table 2. Regression analysis includes 1,987 observations (female 1,000 and male 987 respondents). The average age of male respondents is higher (47 years) than that of females' (44 years). Slightly more than one-third of women can read and write. The male literacy rate (61%) is almost double that of women (33%), with average years of

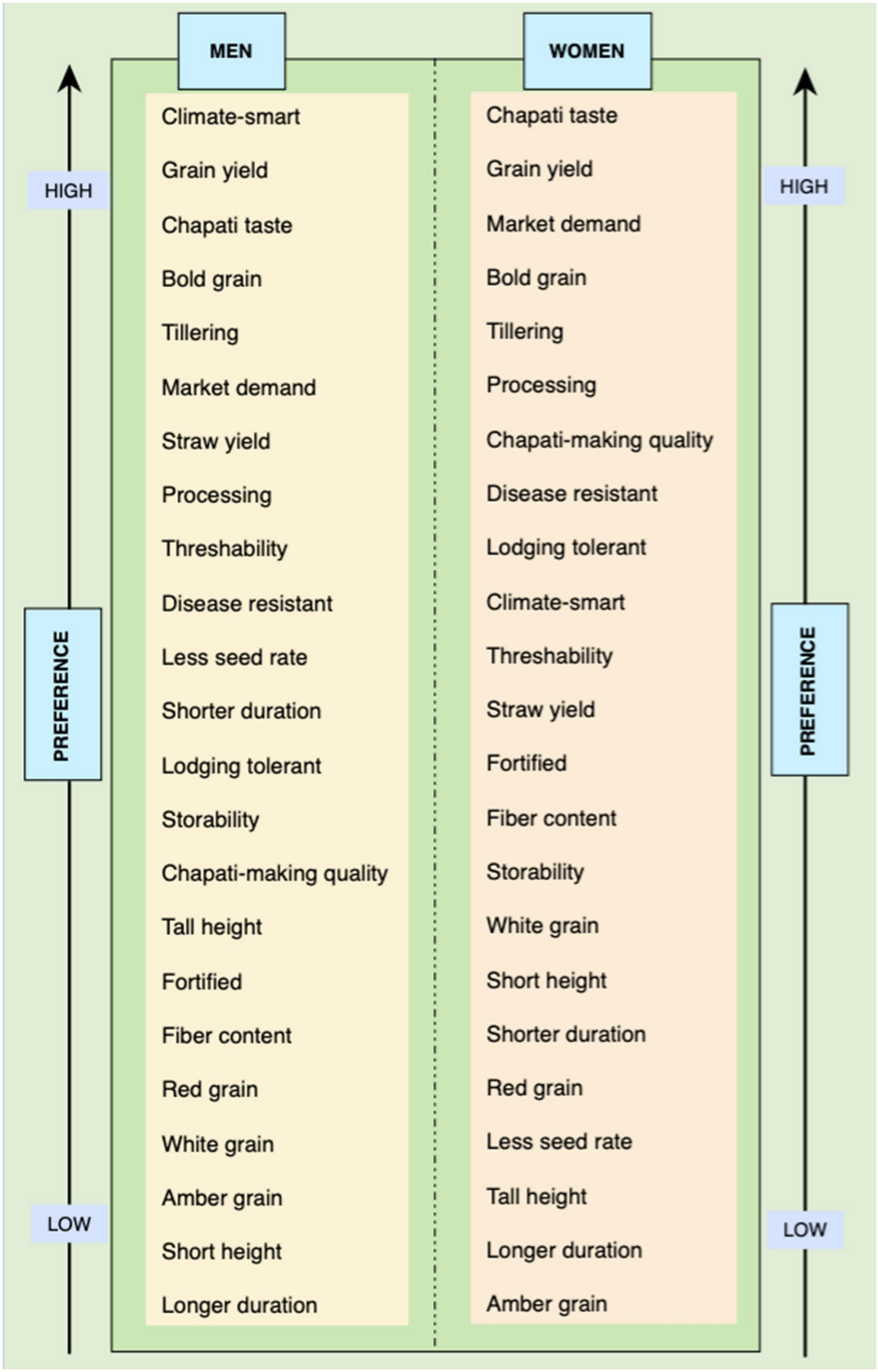

FIGURE 4
Order of wheat trait preferences, difference between women and men.

schooling for women (2.8) half that of men (5.6). Almost 88% of men reported themselves as the head of household, while that proportion was 9.4% for women. About 63% of the survey households belong to other backward castes (OBC), while about 22% are scheduled castes (SC), and 15% general caste (GC). Similarly, the overwhelming majority (92%) follow Hinduism and the remaining 8% follows Islam among the survey households. The average area reported under wheat cultivation is just above one acre.

More than half of the male respondents reported that they introduced at least one new wheat variety in the last 5 years, while that is outnumbered above two-thirds in the case of the female respondents. Of the 26 challenges listed related to wheat farming, the average number of challenges women reported is slightly higher (13.4)

TABLE 2 Summary of the independent variables used in the logistic regressions.

Variables	Notation	Option	Value	Principal men		Principal women	
				Mean	%	Mean	%
Age	AGE			47.4		43.6	
Education	EDU			5.6		2.8	
Marriage status	MARRY	Otherwise	0		8.7%		8.7%
		Married	1		91.3%		91.3%
Household head	HEAD	No	0		12.4%		90.6%
		Yes	1		87.6%		9.4%
Caste group	CASTE	Scheduled caste	1		21.8%		21.8%
		Other backward caste	2		62.9%		62.9%
		General caste	3		15.3%		15.3%
Religion	RELIGION	Muslim	0		7.7%		7.7%
		Hindu	1		92.3%		92.3%
Wheat cultivated area (acre)	AREA			1.29		1.14	
Cultivated at least one new wheat variety over the last 5-year period	NEWVAR	No	0		45.6%		32.5%
		Yes	1		54.4%		67.5%
Summative index for the 26 wheat production constraints	WPCONS			11.5		13.4	
Summative index for the 12 household amenities	ASSET			6.6		6.6	
Ate less food than thought over 12 months	LESSFOOD	No	0		66.9%		48.2%
		Yes	1		33.1%		51.8%
Waterlogging problem in any area of the land	WRLOG	No	0		83.1%		83.0%
		Yes	1		16.9%		17.0%
Soil salinity problem in any area of the land	SOILSAL	No	0		88.3%		88.2%
		Yes	1		11.7%		11.8%
Flood hazard category	HAZARD	High to very High	1		20.1%		19.8%
		Moderate	2		40.4%		40.5%
		Low to very Low	3		39.5%		39.7%
Agro-climatic zone	AGROZONE	Zone I	1		40.2%		39.9%
		Zone II	2		20.4%		20.3%
		Zone III(a)	3		19.8%		19.9%
		Zone III(b)	4		19.7%		19.9%

than that of men (11.5), indicating that women are exposed to more challenges than men. The average ownership of household assets is slightly higher than 50% of the 12 items asked during the survey. Due to many circumstances, especially due to less food production at the household level, one-third of men and slightly more than half of women stated lower food consumption over the past 12 months. In summary, male respondents were found to be relatively older, more educated, less exposed to wheat production constraints, and would consume more food. On the other hand, women respondents are better informed on the constraints of wheat farming and are more involved in the labor market in the village, even if they are a little behind in other demographic indicators, especially age and education, which could be considered having better knowledge, indicating that their experience matters. At the ecological level, the respondents are distributed in different categories of hazard and agroclimatic zones.

3.3 How do these factors influence the gendered trait preferences in wheat?

As mentioned earlier, the regression results are organized into four categories of independent variables based on their personal characteristics (age, education, marital status and household headship), household characteristics (caste, religion, introduction of new wheat varieties, household assets and access to food), agronomic (wheat cultivation area, wheat production constraints, waterlogging condition and soil salinity), and ecological (hazard categories and agro-climatic zones) characteristics. Details of the regression results are presented in Appendix Table 1; in this section, we illustrate the coefficients of binomial logistics regression in each of the categories, with a focus on statistically significant *p*-values for some key traits.

3.3.1 Effects of personal characteristics

The results show that personal attributes influence trait preference in different ways, some have a positive association, while others have negative (Figure 5). It is evident that as women's age increase, their preference for disease resistance and red[1] grain color traits decrease. In the case of men, the preference for threshability and white-colored grain decreases with age. Men's education negatively influences the preference for the storage trait and positively for the red grain trait, while women's education enhances the preferences for wheat varieties that are fortified with minerals for better nutrition. On many wheat traits, the marital status of women and men had no significant influence; however, married men tend to prefer less on those varieties that have high demands in the market, and married women tend to prefer less lodging-resistant varieties. For household management role, women who are also household managers are less likely to prefer resistance to lodging, shorter duration, and zinc-fortified wheat varieties. For men, the household management would increase their preference for the zinc-fortified trait (by 1.8 times).

3.3.2 Effects of household characteristics

Whether the respondent had recently introduced new wheat varieties (in the last 5 years) has an implication in understanding their traits' preferences. For example, men who had introduced at least one new wheat variety in the last 5 years are less likely to prefer wheat traits such as high grain yield (0.5 times), longer duration (0.6 times), amber[2] grain color (0.7 times); however, they are more likely to prefer high straw yield (1.8 times), good tillering varieties (1.9 times), superior chapati taste (1.9 times), and better market demand (1.7 times). In the case of women, those who had introduced at least one new wheat variety over the last 5 years are likely to prefer the grain yield trait (4.1 times), straw yield trait (1.4 times), lodging tolerance trait (1.7 times), disease resistance trait (1.6 times), the zinc-fortified wheat varieties (1.4 times), chapati making quality (1.8 times), and better fiber content (1.7 times); however, their preferences were less in bold grains (0.6 times), longer duration (0.6 times), lower seed rate (0.7 times), and storability traits (0.5 times) traits.

With respect to the ownership of household assets, the effects on trait preferences for both men and women are limited. The number of household assets does not have a significant influence on women's trait preferences; however, men tend to prefer more traits of threshability and prefer less resistant to lodging, and traits of amber and red grain color when the number of household assets increase. Likewise, religion seems to have implications for gendered trait preferences; being a woman following the Hindu religion, the preference for (i) high grain yield increases by 2.4 times, (ii) bold grain increases by 1.8 times, but the preference for (iii) high straw yield trait decreases by 0.5 times. Likewise, being a Hindu man, the preference for the good tiller attribute decreases by 0.5 times (Figure 6).

The respondent who ate less food than they thought over the last 12 months, a proxy for household food insufficiency, seems to influence the preference over several traits significantly, but the relationship is not straightforward, which varies by trait. The household food insufficiency tends to improve the preference of women for traits such as high grain yield (4.4 times), taller height (1.5 times), longer duration (2.1 times), threshability (5 times), storability (2.4 times), high quality of grinding (5.7 times), and better market demand (3.7 times). In a similar situation, men tend to prefer high straw production (1.5 times), good tillering (1.6 times), and superior chapati (1.8 times).

Household food insufficiency significantly decreases the preferences of men and women for many traits of wheat. For example, in food-insufficient households, a reduction in men's preference for lodging resistance (0.4 times), disease resistance (0.3 times), lower seed rate (0.7 times), threshability (0.5 times), amber grain color (0.3 times), red grain color (0.4 times), zinc fortified (0.5 times), chapati making quality (0.4 times), and better market demand (0.5 times) is seen. Likewise, women in food-insufficient households prefer less in traits such as tillering (0.4 times), better climate adaptation (0.1 times), less seed rate (0.7 times), red grain color (0.8 times), zinc fortified (0.6 times), chapati making quality (0.5 times), and better fiber content (0.7 times).

The caste group also influences the gender preference for some of the traits. For example, women from SC and OBC had a higher preference for grain yield potential (3.8 and 4.4 times, respectively, compared to those from GC), and climate adaptive traits (2.0 and 1.7 times, respectively, compared to GC); however, their preference for the grinding trait was reduced by 0.5 times, compared to GC. This could be because GC people are relatively better off, meaning they have alternative livelihood options, which may entail that yield potential specifically from wheat may not be of their interest compared to that of people from the OBC and SC groups.

3.3.3 Effects of agronomic characteristics

Figure 7 presents the agronomic characteristics that influence wheat traits by gender. The wheat crop area at the household level had no significant influence (at the 5% confidence interval) on the trait preferences of men and women. The summative value of wheat production constraints seems to positively influence the preference of both men and women for many wheat traits, indicating that greater exposure to production constraints led to the preference of all traits, probably believing that the perceived production challenges they face are solved.

The preferences of women and men for many traits of wheat differ when their farmland had problems such as waterlogging and soil salinity. The influence of such conditions on their preferences is not straightforward and varies by traits as highlighted in Figure 7 and Appendix Table 1. In such conditions, women seem to prefer more nutritional traits than agronomic traits.

3.3.4 Effects of ecological characteristics

Finally, the association between gendered trait preferences with flood hazards and agroecological zonation is provided in Figure 8. In the case of flood hazards, we are interested in the adaptive weather trait. We noted that increasing flood hazard intensity tends men to prefer weather adaptive traits (5 to 6 times), but not necessarily the situation prompts women to do so. The preferences for gender traits vary by agroecology. Compared to Zone I (for the four agroecological zones in Bihar), the preference of men for the adaptive weather trait is 5.6 times more in Zone II and 4.8 times more in Zone IIIb, while for Zone IIIa, this relationship is negative, meaning that men are less likely to prefer the adaptive weather in Zone IIIa, compared to those

1 Some farmers identify this grain color as red.

2 Some farmers identify this grain color as yellow.

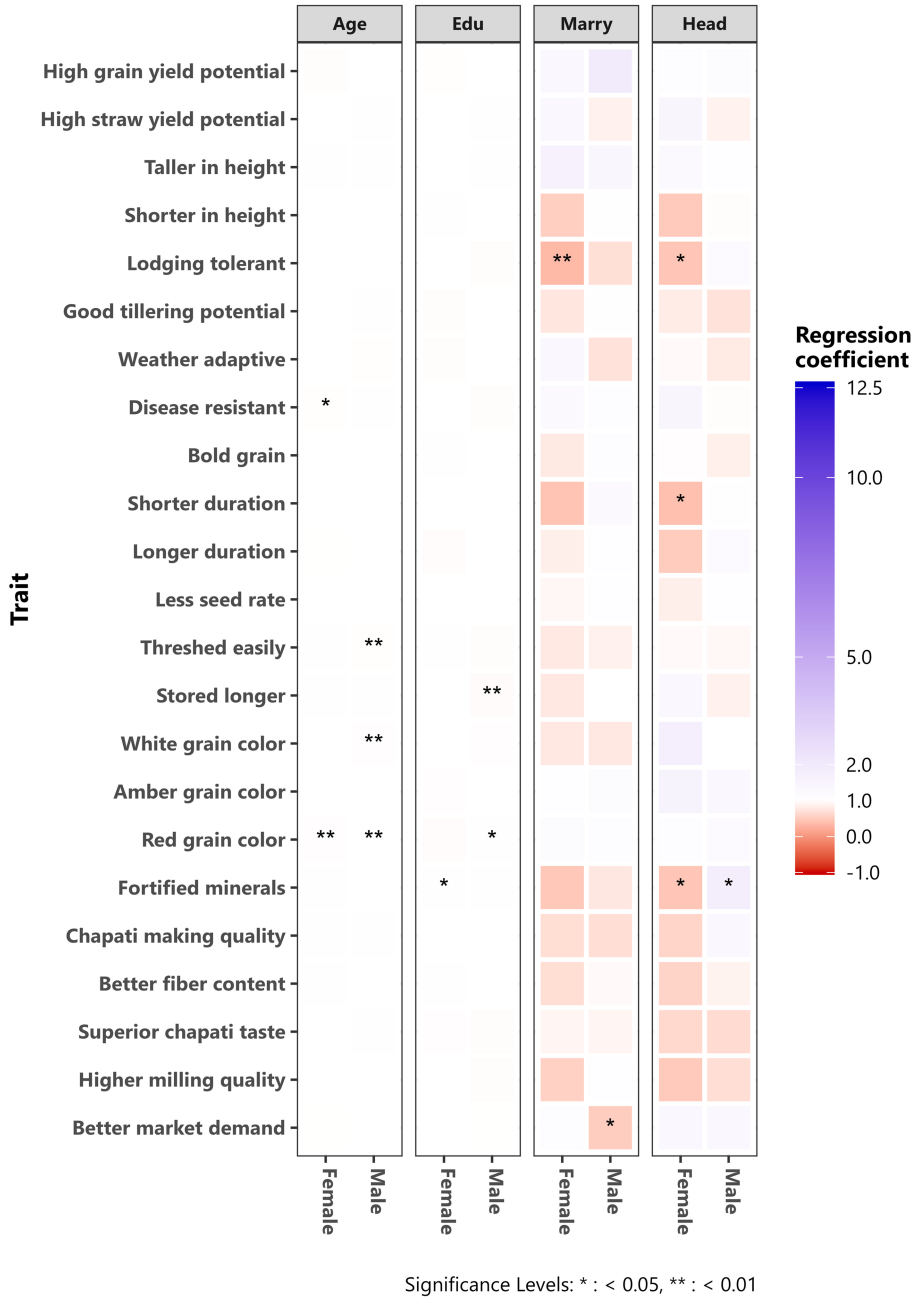

FIGURE 5
Personal attributes influencing wheat trait preferences.

who live in Zone I. The demands of bold grain trait in those zones are also greater, compared to Zone I. Women living in all agroecological zones have a similar preference for weather adaptive traits, as none of them showed statistically significant results.

4 Discussion

Our study seeks to broaden the notion of women traits versus men traits and dived deep into the matter by looking at what other social, household, agronomic and ecological factors influence if the women and men farmers had a chance to choose traits. We observed that gender continues to matter in trait preferences, but it goes beyond the gender of farmers and is subject to the factors that help build farmers' livelihood in broader social, economic, cultural, and ecological settings, which is in confirmation with other recently conducted studies (Teeken et al., 2021). The paper reports that several factors influence trait preferences, and the influence of these factors varies for women and men farmers. The factors are interrelated and organized in a nested fashion of individual, household, agronomic, and ecological (landscape) aspects of the socio-ecological model. Preferences for specific traits (we examined) increase when a person is exposed to more challenges in wheat production. Flood hazard intensity in the research area may have led both women and men to choose a weather-adaptive trait.

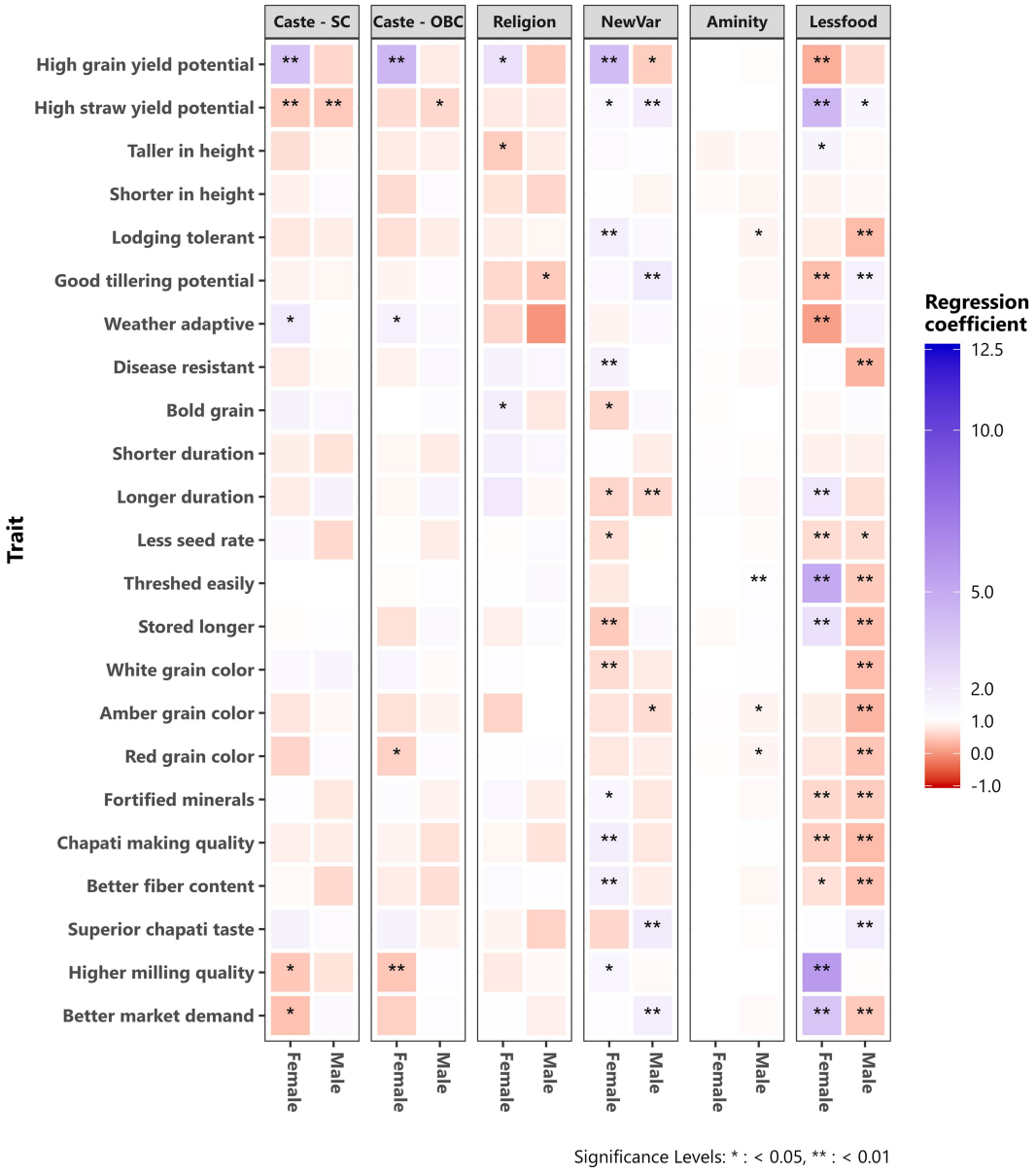

FIGURE 6
Household characteristics influencing wheat trait preferences.

The findings are consistent with previous studies conducted on this matter. The literature shows that trait preferences differ by labor division, contrasting the roles and responsibilities women and men farmers perform for various crop production or post-harvest activities (Weltzien et al., 2019). The differences in trait preferences between women and men farmers may also be because of their involvement in alternate (or complementary) livelihood activities. It is evident in our study that men prefer higher straw yield and good tillering traits, which would be because men tend to keep more larger livestock such as cattle and buffalo than women, requiring more straw for feeding (Quisumbing et al., 2015; Galiè et al., 2019; Bonis-Profumo et al., 2022).

The individual attributes of age, education, and marital status, which largely contribute to someone's agency and capability to influence on decision-making (Sen, 1985; Gangas, 2016); it is important how these factors play a role to prefer specific traits than others. In our study, it was observed that aged women are less likely to prefer red trait. Red trait contributes to high protein content, which gives chapati with greater chewiness and higher tearing resistance (Panghal et al., 2019). Thus, women who are aware of these grain qualities may not like red wheat trait. As evident in Figure 2, Shri Ram 303, UP262, and HD2967 are the three mostly grown varieties in the study area. All these varieties have desirable protein content (Siddiqi et al., 2021), which might be the source of this knowledge for trait preference. Likewise, educated women are more likely to prefer mineral-fortified varieties, while that is not the case for men and are more likely to prefer red grain trait. Data further shows that marital status has no significance on specific wheat trait preferences.

These diverse influences of men and women's personal attributes (associated with their agency capability) imply to what

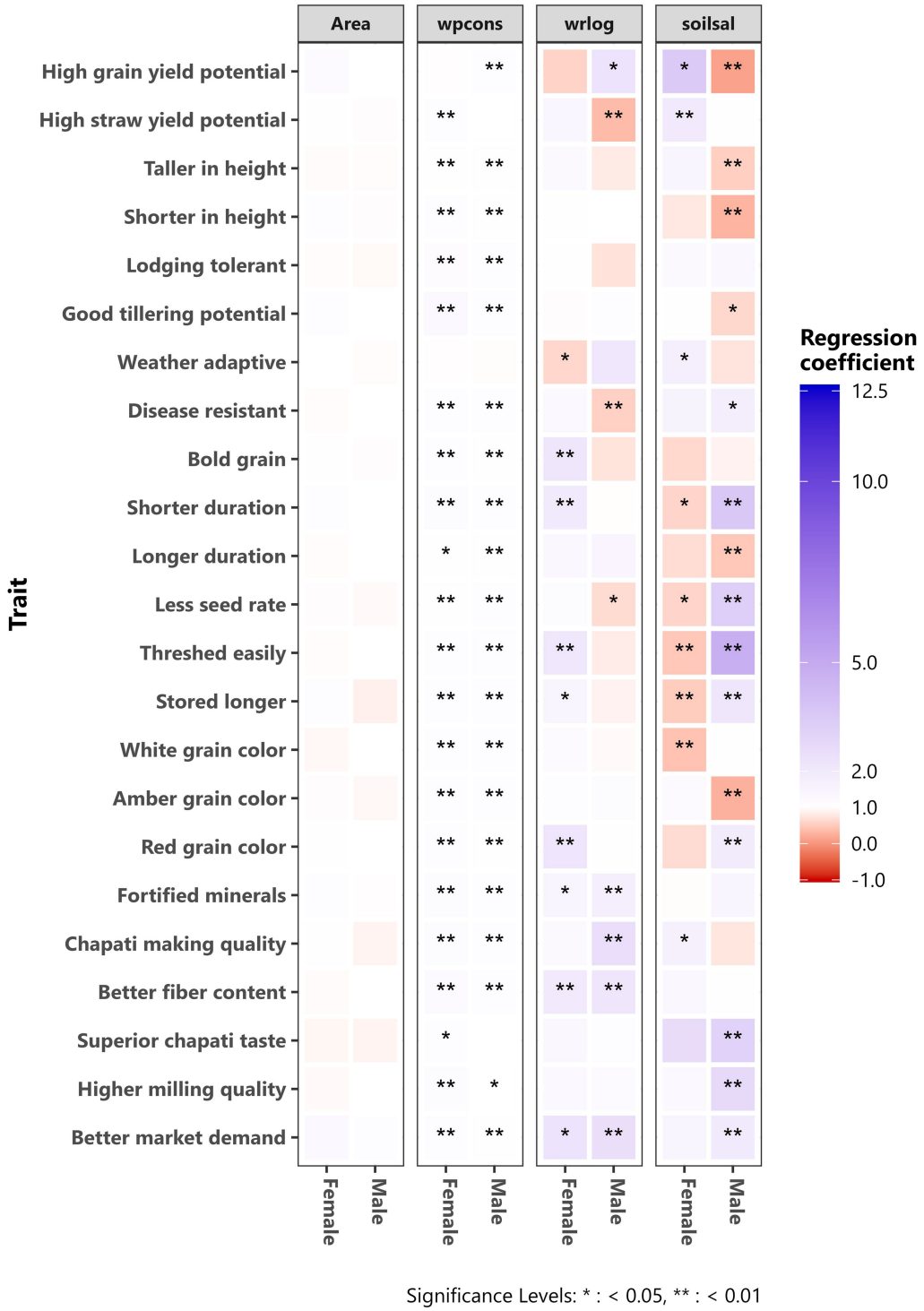

FIGURE 7
Agronomic characteristics influencing wheat trait preferences.

they would provide information if consulted during demand collection. As such, the agency and capability are inherent qualities of individuals to have different trait preferences. However, equally important is how they are taken into consideration as feedback to feed into target product profile development, the process that is governed by the wider social, cultural, and institutional environment the individuals live in. It further implies that they are larger issues of how gender and social differences are included in the agricultural innovation process.

The results show some implications of religion for gendered trait preferences. Even though religious beliefs may not directly impact the trait preferences, they can certainly shape food and dietary choices through cultural norms and individual convictions (Minton et al., 2019; Mekoth and Thomson, 2020). These inclinations may vary depending on

FIGURE 8
Ecological characteristics influencing wheat trait preferences.

the extent of religious involvement. In our investigation, we found that Hindu women exhibited a stronger inclination toward traits such as high grain and straw yield, as well as bold grain. This tendency could be linked to their engagement in religious practices, including fasting, and the common use of wheat flour in the preparation of *'Prasad'* (food offered to deities). For instance, Hindu women might opt for wheat chapati over rice during *'Ekadashi'* fasting rituals. Similarly, they might be tasked with preparing *'Prasad'* made from wheat flour during festivals. Nevertheless, further research is recommended to comprehensively understand and validate these findings.

This study also shows that the gendered trait difference also depends on their behavior of allowing new varieties on their farm. Those who introduced new varieties in the last 5 years preferred high yielding (both women and men), better cooking quality (for women), and better taste (for men) traits. Looking at the mostly grown varieties in the areas, HD 3226 (released in 2019) is known to have high yielding, high protein, superior grain quality, disease resistant, cooking quality, and taste traits (Yadav et al., 2019). Krishna and Veettil (2022) report that women opt for grain quality attributes (better cooking quality, supporting our results). The same study suggests that women

tend to explore newer varieties with different traits due to their close association with their concerns about food insecurity. This also relates to another finding of this study how farmers experiencing production constraints tend to opt for newer varieties, as a way of trying new things as a coping strategy.

Morris and Bellon (2004) observed that farmers' varietal preferences vary according to seasons, locations, and individuals. This variation in the perception of varietal traits among individual farmers determines the rate of adoption of improved varieties (Kalinda et al., 2014). Tikadar and Kamble (2021) report that farmers prefer high-yielding improved varieties under low input conditions. They also point out farmers' adaptations toward practicing conservation tillage and drought-resistant varieties to address climate risks. Singh et al. (2013) and Singh et al. (2014) observe that farmers prefer improved high-yielding varieties, but due to the higher cost of production caused by expensive improved seeds, farmers are discouraged to opt for such varieties, which is also in line with Kumar et al. (2018), who report the use of substandard seeds due to the high cost of improved varieties in eastern India.

One of the main policy implications and a significant contribution (to science) of this analysis is the dynamic interface between women's traits preferences, involvement in agriculture in general, but in wheat production in particular, and their limited access to agricultural extension and training services. It is evident that women tend to face a higher number of constraints and challenges in wheat production and thus have preferences over the traits required to cope with these challenges. This is coupled with the higher number of women involved in wheat production, compared to men who are involved in cash crop production or other non-agricultural jobs like wage labor within or outside of their village. For instance, women's labor force participation in agriculture is 65% in India, which is much more than the participation of men in the same sector (50%; Pattnaik et al., 2018). Due to the limited opportunities for women to leave agriculture, their participation in agriculture will not change, compared to that of for men. Therefore, increased participation of women in training and extension services is important to continually improve their management capacity and perform agricultural job better. However, in the situation of already limited human resources employed in India's agricultural extension system, extension workers are very few (Nandi and Nedumaran, 2019). It is difficult for male extension workers to reach out to female farmers due to the cultural taboo for women not to contact an 'external' man. Moreover, it is usually men who receive training and extension services, especially those from the government, while it is women who are involved in agriculture more than men, which further marginalizes women and have more labor burden. A solution policymakers can consider is hiring more female extension workers or targeting more women farmers (in any way) in relevant training and extension activities, getting them in the (agricultural) community meetings where strategic decisions such as seed demand Research Topic and discussion on trait prioritization occur (Suri and Gartaula, 2023).

Another robust indication this analysis suggests is the influence of agroecological zones for wheat trait preferences differing for women and men farmers. In a study carried out in Nigeria in the case of Cassava, Teeken et al. (2018) have similar findings, significant regional differences in trait preferences. This seems obvious but has a great implication for crop improvement and breeding programs in considering regional parameters for the development of the target product profiles and market segmentation.

Putting together, the diversity of trait preferences that are influenced by the personal, household, agronomic and ecological characteristics of the men's and women's livelihood system. These findings are very critical for developing target product profiles, which are subject to specific market segments that would also include other parameters like climate, farming system, market development, agronomic practices, technologies in use, and so on. These human dimensions of traits preferred by women and men farmers could be considered to select packages of traits to develop target breeding product profiles for specific market segments. A recent report produced by the CGIAR System Organization highlights that the existing breeding program assessment tool does not have a strong mechanism that embraces the systematic use of product profiles, continuously updated market intelligence, and agile stakeholder consultations, to ensure that new varieties would meet the requirements and preferences of women and men farmers, consumers, traders, processors, and others along the value chain (CGIAR System Board, 2018). Therefore, the results from this analysis will contribute to narrow down the gap identified in the above-mentioned report. As wider implication, this study provides an important lesson for the research organizations like CGIAR and other national system who have crop breeding mandates.

5 Conclusion

Our study has shown how personal, household, agronomic, and ecological factors influence the preferences of women and men farmers differently for wheat traits. It is revealed that gender plays an important role in determining the preferences of wheat traits. Men prefer wheat varieties that are well suited for extreme climate conditions, followed by higher grain yields and superior chapati taste, while women prefer wheat varieties with excellent chapati making quality followed by higher grain yield and higher market prices. Other socioeconomic, agronomic, cultural and geolocation factors also have a significant effect on traits preferences.

The variations in preference for traits between men and women within the same household can inform the selection of traits for developing target product profiles tailored to specific market segments. For instance, the individual agency and capabilities to make decisions for the male and female farmers significantly influence their preferred traits, underscoring the importance of considering their perspectives in target product profile development and market segmentation. This broader perspective extends to how gender and social disparities are integrated into the agricultural innovation process.

Moreover, these findings address a gap in the current assessment tool CGIAR uses for breeding programs, which lacks a robust mechanism for systematically incorporating product profiles and market segmentation. This gap highlights the need to ensure that new varieties align with the requirements and preferences of both male and female farmers.

While this study solely relies on structured surveys, it could have been enhanced by complementing quantitative data with qualitative insights gathered through a mixed research design. Integrating both types of data would provide a more comprehensive understanding of trait preferences and decision-making processes among farmers.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Institutional Research Ethics Committee (IREC), CIMMYT. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

HG: Conceptualization, Project administration, Supervision, Writing – original draft, Writing – review & editing. KA: Data curation, Formal analysis, Methodology, Writing – review & editing. NK: Data curation, Visualization, Writing – review & editing. SM: Validation, Writing – review & editing. RS: Funding acquisition, Validation, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The reviewer AS declared a shared research partnership group [CGIAR] with the authors HG, NK, and RS to the handling editor.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2024.1284817/full#supplementary-material

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