

Gender (in)equity and the adoption of farm machinery: Opportunities and trade-offs in Bangladesh livestock systems

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ABSTRACT

Agricultural mechanization can improve wellbeing and livelihoods in agrifood systems, but its benefits may not be evenly shared between women and men. This is a concern given the increased interest in agricultural mechanization in development programs. In this study, we analyzed data from 373 livestock producers in Bangladesh to assess the associations between adopting mechanized fodder choppers and gendered time-allocation, participation in decision-making, and control over livestock income. Accounting for observed heterogeneity between adopters and non-adopters, we find that the use of mechanized fodder choppers was associated with husbands claiming more influence over the use of livestock income. Adoption was also correlated with women's time savings in livestock production, which they used for additional resting. While the associations in this study should not be interpreted as causal relationships, we conclude that the gendered outcomes of the adoption of mechanized fodder choppers can be complex. Development programs promoting farm machinery may need to consider ways that allow women to capture benefits while employing safeguards to prevent a potential weakening of women's agency in livestock production.

1. Introduction

The use of mechanization in smallholder agriculture is growing, especially in Asia (Diao et al., 2020). Increasing labor scarcity and outmigration in rural areas, paired with aging farmer population and rising agricultural wage rates are contributing to increased adoption of labor-saving agricultural technologies on small-scale farms (Rola-Rubzen et al., 2020). Although positive agronomic and socio-economic effects of the use of agricultural machinery on smallholder farms are well documented (e.g., Aryal et al., 2020; Jena and Purna, 2023; Paudel et al., 2019), gender disparities in access to and use of agricultural machinery persist (Mottaleb et al., 2016; Theis et al., 2019). Adoption barriers faced by women farmers include limited information exposure, inadequate access to extension and credit, as well as gender inappropriate technology-specific characteristics (Vemireddy and Choudhary, 2021). In addition, sociocultural conventions, hegemony, and beliefs about gender roles, as well as a lack of agency in intra-household decision-making and control over farm resources hinder

a more widespread adoption of agricultural machinery among women (Rola-Rubzen et al., 2020).

Furthermore, gendered impacts of the use of agricultural machinery are not well understood. While empirical research mostly focused on the implications for women's workload and earnings (Afridi et al., 2023; Farnworth et al., 2020; Gartaula et al., 2020; Theis et al., 2019), evidence on how the use of farm machinery affects women's empowerment within the household is scarce and inconclusive (Farnworth et al., 2020; Fischer et al., 2018; Theis et al., 2019). This is a critical gap, since women's empowerment is a development objective in itself and can contribute to the achievement of complementary global development objectives (FAO, 2023). For instance, women's empowerment can enhance farm productivity (Mobarok et al., 2021), household socio-economic wellbeing (Vemireddy and Choudhary, 2021), and food and nutrition security (Beriso et al., 2023; Sraboni et al., 2014).

In this study, accounting for observed heterogeneity between adopters and non-adopters, we assess the associations between the use of mechanized livestock fodder choppers and women's empowerment in

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livestock production in Bangladesh. As proxy indicators for women's empowerment, we used women participation in household decision-making, control over the use of household income, as well as time allocation in livestock production (cf. Akter et al., 2017; Eissler et al., 2022; Haque et al., 2021). Given the observational and cross-sectional nature of our data, the associations found in this study should not be interpreted as causal. Nonetheless, our results aim at contributing to the design and implementation of development programs that enable women to capture benefits from the use of farm machinery, while also employing safeguards to prevent a potential weakening of women's agency in livestock production.

2. Gender roles in livestock production and farm mechanization in Bangladesh

More than half of the agricultural workforce in Bangladesh are women (Biswas et al., 2022). However, cultural and religious practices, referred to as purdah, involve the separation of women from public spaces and male-dominated environments which often restricts their participation in social and political life. Purdah practices also disfavor women engagement in household decision-making and control over farm assets (Jennings et al., 2022), and limit their employment choices and income generating opportunities (Farnworth et al., 2020; Nazneen, 2024). In this context, some agricultural tasks are considered inappropriate for women, especially those that involve interaction with men or being in public spaces (Asadullah and Zaki, 2016). Women are therefore less involved in field work and crop production, but engage in activities around the homestead, such as home gardening, post-harvest processing, selection and storage of seeds, as well as poultry production and livestock rearing (Biswas et al., 2022).

Livestock production is crucial to support household income and improved nutrition in Bangladesh (Banda and Tanganyika, 2021; Hosain and Khan, 2020; Moller et al., 2023), but social and cultural norms also shape the gendered division of labor and decision-making in livestock rearing. While the production and processing of animal feed, and fodder purchasing largely fall under men's responsibilities, women are mainly engaged in tasks around the homestead such as animal cleaning and feeding (Biswas et al., 2022), as well as fodder chopping (Islam et al., 2019).

To reduce the workload and drudgery of livestock producers, as well as enhance fodder quality, and livestock productivity, mechanized fodder choppers have been promoted in small-scale agriculture (Fischer et al., 2018). Their use can affect different dimensions of women's empowerment directly or indirectly, by altering gendered arrangements in decision-making, workload and time allocation, as well as control over resources and income (Table 1). To assess whether these changes are beneficial or detrimental for women's empowerment, we formulate and test three hypotheses. First, we expect women to benefit from reduced time allocation in feed preparation (Hypothesis 1) if they can capture time savings related to the adoption of mechanized fodder choppers. Second, we expect the adoption of mechanized fodder choppers to strengthen women's role in household decision-making (Hypothesis 2) if its use stimulates women engagement in livestock production. Third, we expect women to gain control over livestock income (Hypothesis 3) if the adoption of mechanized fodder choppers entails productivity gains and if women can capture these.

3. Methods

3.1. Data base

The study used farm household data. Due to the lack of reliable estimates of adoption rates of mechanized livestock fodder choppers on small-scale farms in Bangladesh, the population consisted of a non-random sample of households with previous exposure to different projects in relation to promotion and capacity building activities for the use

of farm machinery conducted by the International Maize and Wheat Improvement Center (CIMMYT) and its partners.¹ This approach was employed to ensure that the sample contained a sufficiently large number of users of mechanized fodder choppers.

The initial population included 780 farm households from 35 districts in Bangladesh (Table 2) from which 560 households were interviewed. For the analysis, we relied on 373 households for which interviews from both wife and husband could be completed. Interviews from both spouses were a precondition for constructing variables on intra-household differences in time use, influence in decision-making and control over income in livestock production.

3.2. Household survey

Household surveys consisted of two questionnaires; one intended for the wife, and one for the husband residing in the household (Table 3). Both questionnaires included sections on gender roles in livestock management, decision-making, control over income, and individual time allocation in the 24 h preceding the interview, i.e., from 5am the previous morning to 5am on the day of the interview. The husband questionnaire further included sections on socio-demographic household characteristics, livestock endowments and management, and applied fodder processing practices. The survey was addressed to both wife and husband individually with the objective of capturing nuanced perceptions of the effects of mechanized fodder choppers on gendered roles in livestock production. Conducting independent interviews with several individuals from the same household is gaining prominence in empirical quantitative gender research (e.g., Ogolla et al., 2022).

3.3. Data collection

Given the geographic dispersion of producers across different divisions, the study relied on a phone survey for data collection, which was implemented in October 2023 by a team of trained enumerators. Considering the social context and cultural norms in Bangladesh, the enumerator team included both male and female members. Male enumerators conducted interviews with male farmers, while female enumerators interviewed female respondents.

There are several challenges and potential shortcomings related to the conduct of phone surveys. First, although mobile phone use and ownership is growing, including in Asia (ITU, 2024), there is a risk of coverage bias, i.e., excluding segments of the population that do not have access to mobile phones. This may be problematic if the cellphone ownership and access are correlated to treatment and outcome variables of interest (Ambel et al., 2021). In addition, non-response bias, i.e., observations that cannot be contacted or interviewed successfully, can further undermine the sample representativeness. While nonresponse also occurs in face-to-face interviews, it tends to be higher in phone-based interviews (Gourlay et al., 2021), and can also introduce bias since respondents can systematically differ from non-respondents (Ambel et al., 2021). Finally, a lack of privacy during phone interviews can yield biased replies, especially when covering sensitive topics, such as gendered roles in control over income (Alvi et al., 2022).

During the data collection for this study, the following measures were taken to minimize the risk of the above limitations. To reduce the impact of nonresponse bias, the enumerator team made persistent efforts to contact as many households as possible, including multiple call attempts at different times of the day, sending reminder messages or

¹ Farmer contact lists were gathered from organizations engaged in livestock management initiatives including the Department of Livestock Services (DLS), the Cereal Systems Initiative for South Asia–Mechanization Extension Activity (CSISA-MEA), and the Livestock and Nutrition Activity (LAN) implemented by Agricultural Cooperative Development International/Volunteers in Overseas Cooperative Assistance (ACDI/VOCA).

Table 1
Potential implications of the adoption of mechanized fodder choppers on women’s engagement and influence in livestock production.

	Implications on gendered ...	Assumptions	Hypothesis	Supporting evidence
Use of mechanized fodder choppers	Time allocation	Women capture time savings	H1: MFC reduce women’s time allocation in livestock production	(Afridi et al., 2023; Farnworth et al., 2020; Gartaula et al., 2020; Theis et al., 2019)
	Decision-making	Women take up more responsibilities in livestock production	H2: MFC enhances women’s influence in decision-making	Theis et al. (2019)
	Control over income	Women capture increases in livestock productivity	H3: MFC enhance women’s control over livestock income	Theis et al. (2019)

Notes: Stylized implications of the adoption of mechanized fodder choppers for women’s engagement and influence in livestock production, related assumptions and testable hypotheses (H1 -H3). MFC = mechanized fodder choppers.

Table 2
Distribution of the study population, interviewed households, and share of mechanized fodder chopper adopters by administrative units of Bangladesh.

Division	Initial population		Interviews conducted			
	No. households	No. districts	No. households	Response rate (%)	No. of husband and wife pairs	Share of adopters (%)
Barishal	68	3	45	66	30	13
Chittagong	190	9	150	79	104	35
Dhaka	129	9	71	55	35	83
Khulna	297	8	215	72	151	54
Rajshahi	96	6	71	74	53	89
Total	780	35	560	71	373	54

Notes: Observations with completed wife and husband surveys are used to construct intra-household differences in time use, influence in decision-making and control over income. The difference between total interviews and observations used are either single headed households (male or female), or households for which either the wife or husband interview was not completed.

Table 3
Content of the husband and wife questionnaires.

Section	Main variables of interest	Contained in ...
Socio-demographic household characteristics	Spouses’ age and education levels, household size and place of residence	Husband questionnaire
Livestock endowments and management	Household’s herd size of small and large livestock, annual sales and purchases	Husband questionnaire
Fodder processing activities employed by the household	Household’s adoption of mechanized fodder choppers, level of fodder production on own farm, and fodder purchases	Husband questionnaire
Gender roles in livestock production	Individual role in management, decision-making, and control over income	Husband and wife questionnaire
Time allocation	Individual time use (30-min interval) during 24-h preceding the interview	Husband and wife questionnaire

Notes: The husband questionnaire was addressed to the husband/male household head of the family, while the wife questionnaire was addressed to the wife of the male household head.

scheduling call-backs at more convenient times. The final response rate of the survey was 71 %, which is above the average response rates reported by synthesis studies on the conduct of phone surveys during the COVID-19 pandemic. For instance, Gourlay et al. (2021) reported 60–93 % response rates for 5 countries in Africa, while Henderson et al. (2020) reported 3–48 % response rates for computer assisted telephone interviews in 13 countries. To ensure privacy, enumerators received specific training to prioritize the comfort of the women respondents during interviews. Each interview began with the enumerator confirming whether the respondent was in a private setting and felt comfortable speaking openly. If the respondent indicated that she was not in a private environment or did not feel comfortable, the enumerator was instructed to reschedule the interview.

Despite these efforts, non-coverage and non-response-bias may apply to households that differ systematically from households that are contained in the final sample of our study. In the absence of reliable data on

cellphone ownership in combination with households’ level of engagement in livestock production and use of mechanized fodder choppers, the coverage bias was difficult to quantify. For instance, relatively poorer and less educated households may be underrepresented in our sample (Ambel et al., 2021). The findings presented in this paper should be interpreted against this background.

3.4. Empirical strategy

The aim of this study was to analyze the associations between the adoption of mechanized fodder choppers and women’s empowerment in livestock production in Bangladesh. Women’s empowerment in livestock production has been operationalized through the Women’s Empowerment in Livestock Index (WELI) which contains six main dimensions, including decision-making in agricultural production and nutrition; access and control over resources, income and opportunities; and workload and control over time (Galiè et al., 2019). In this study, we focused on specific elements from the wider WELI, namely (i) time allocation for fodder chopping activities of both women and men farmers, (ii) gendered roles in household decision-making in livestock production, and (iii) gendered control over livestock-based household income.

Given the observational nature of our data, the study follows a quasi-experimental design. Since the adoption of mechanized fodder choppers is not randomly distributed among observations, we employed Inverse Probability Weighted Regression Adjustment (IPWRA) (Wooldridge, 2010) to estimate the ‘average treatment effect on the treated’ (ATET). IPWRA accounts for missing counterfactual and observed confounders that may simultaneously influence the decision to adopt mechanized fodder choppers and the respective outcomes. IPWRA has been employed by a range of studies assessing the effects of technological innovations, including mechanization in agriculture (e.g., Paudel et al., 2023).

IPWRA rests on three main assumptions. The first is the conditional independence assumption which stipulates that selection into treatment (adoption) is solely based on observable characteristics. The second assumption is the common support assumption which states that observations with the same covariates have a positive probability of

assignment into both treatment or control group (Heckman et al., 1999). The third assumption is the independent and identically distributed (i.i.d.) sampling assumption which assumes that the outcome and treatment of a household are independent of the outcome and treatment status of other households in the population. Given the linear outcome equation

$$Y_i = \alpha + X_i \beta + \varepsilon_i \tag{1}$$

for observations $i = [0 \ 1]$ and related propensity scores $p(x; \gamma)$, the estimation of IPWRA involves two main steps (Imbens and Wooldridge, 2009). First, propensity scores to adopt mechanized fodder choppers from equation (1) are estimated as $e(x) = p(x; \hat{\gamma})$ using binary logistic or probit regression models. Second, liner regression is employed to estimate (α_0, β_0) for non-adopters, and (α_1, β_1) for adopters using inverse probability weighted least squares. Formally:

$$\min_{\alpha_0, \beta_0} \sum_i^N (Y_i - \alpha_0 - \beta_0 x_i) / p(x; \hat{\gamma}) \text{ if } FC_i = 0 \tag{3}$$

$$\min_{\alpha_1, \beta_1} \sum_i^N (Y_i - \alpha_1 - \beta_1 x_i) / p(x; \hat{\gamma}) \text{ if } FC_i = 1 \tag{4}$$

The ATET is the difference between equation (4) and equation (3).

$$ATET = \frac{1}{N_{FC}} \sum_i^{N_{FC}} [(\hat{\alpha}_1 - \hat{\alpha}_0) - (\hat{\beta}_1 - \hat{\beta}_0) X_i] \tag{5}$$

With $(\hat{\alpha}_1, \hat{\beta}_1)$ being the estimated inverse probability-weighted parameters for treated, i.e., households adopting mechanized fodder choppers ($FC_i = 1$), and $(\hat{\alpha}_0, \hat{\beta}_0)$ the estimated inverse probability-weighted parameters for untreated households, i.e., households not adopting mechanized fodder choppers ($FC_i = 0$), and N_{FC} indicating the total number of adopters.

The use of IPWRA with cross-sectional and observational data has potential shortcomings. First, the IPWRA estimator is not robust against unobservable confounders which may simultaneously affect the adoption of mechanized fodder choppers and the outcomes of interest. Second, the establishment of the direction of cause and effect is not straightforward. For instance, households with pre-existing differences in gendered workloads, i.e., households with more husband time-use in fodder preparation may be more eager to adopt mechanized fodder choppers. In response to these pitfalls, the size of potential bias due to unobserved confounders was assessed with the bounding approach proposed by Rosenbaum (2002). This allows estimation of the effect size which any unmeasured variable would need to have on the selection process to render the ATET insignificant. To address potential reverse causality, we present and discuss pre-adoption differences in gendered workload in fodder chopping and ownership of livestock and land.

4. Results and discussion

4.1. Farm and household characteristics

Mechanized fodder chopper adopters tend to have larger herds of livestock, and a higher annual livestock turnover through sales and purchases (Table 4). Adopters tend to own larger areas of land, both around the homestead, as well as on fields away from home. There were no significant differences in the size of farmland dedicated to fodder production in the past growing season between both groups.

Differences in herd size and farmland between both groups may be correlated to gender roles in livestock production. For instance, on farms with larger livestock herds, decision-making may fall under the husbands' responsibility. If these farms also tend to adopt mechanized fodder choppers more often, estimation results focusing on gender roles in livestock production may be biased. To assess potential pre-existing differences, we used our survey data to compare non-adopters to early

Table 4
Land and livestock endowments by adoption status of mechanized fodder choppers.

	(I) Non-adopters			(II) Adopters			(I) vs. (II)
	N	Mean	SD	N	Mean	SD	
Herd size large livestock (no.)	175	5.40	6.18	198	9.85	15.12	***
Annual sales large livestock (no.) ^a	162	3.23	3.58	193	6.10	9.00	***
Annual purchases large livestock (no.) ^a	135	2.53	2.25	157	5.43	19.46	***
Herd size small livestock (no.)	175	2.13	3.63	198	3.74	7.40	***
Annual sales small livestock (no.) ^a	69	2.84	3.94	98	5.31	7.24	***
Annual purchases small livestock (no.) ^a	49	2.06	1.51	69	3.65	8.50	*
Size of homestead land (hectares)	175	0.06	0.07	198	0.10	0.13	***
Total size of farmland (hectares)	175	0.59	0.65	198	0.77	1.10	**
Land under fodder production (hectares) ^a	119	46.48	74.65	192	57.32	90.13	ns
Time since first use of mechanized choppers	.	.	.	198	3.37	2.03	.

Notes: SD is standard deviation. The last column indicates whether mean differences between adopters and non-adopters are significantly different from zero with ***, ** indicating levels of statistical significance of $p < 0.01$ and $p < 0.05$, respectively.

^a Only includes observations for which variables are >0 . Outliers above the 99th percentile were removed.

adopters who had started using mechanized fodder choppers one to two years prior to the survey (Table S1). If gender roles in management of livestock pre-date adoption, we would expect significant differences between both groups in terms of livestock ownership and management. However, we did not find significant differences in husbands' engagement in fodder processing, ownership of livestock and farmland, and total number of livestock owned between early adopters and non-adopters. Against this background, we expect that pre-existing differences in farm and herd size were not systematically linked to the adoption decision. However, we cannot rule out that these differences influenced adoption for a subset of observations.

Regarding households' main socio-demographic features, we did not find significant differences between adopters and non-adopters in terms of wives' or husbands' ages and education levels (with the exception of a higher share of husbands not having attended school among non-adopters), or for the average household size, a proxy for available family labor (Table 5).

4.2. Gendered roles in livestock production

With respect to gendered roles in livestock production, our data indicates that husbands from adopter households had a more active role in managing livestock (Table 6). Although husbands' total time allocation to livestock production did not change with the use of mechanized fodder choppers, husbands' interviews showed that adopters claimed to be more actively engaged in all livestock related activities (meat, milk, and fodder production) compared to husbands from non-adopter households. Husbands also tended to claim to be the main decision-maker and to have influence on decisions on the use of livestock income significantly more often, most notably in milk and meat production. Wives' interviews showed that women allocated about 20 % less time to livestock raising for fodder chopper adopters compared to non-

Table 5
Household socio-demographic characteristics by adoption status of mechanized fodder choppers.

	(I) Non-adopters (N = 175)		(II) Adopters (N = 198)		(I) vs. (II)
	Mean	SD	Mean	SD	
Age of husband (years)	42.68	10.54	42.8	10.1	ns
Age of wife (years)	35.61	9.74	35.16	10.01	ns
Adult household members (no.)	3.73	1.75	3.83	1.8	ns
Children and teenager household members (no.)	1.84	1.29	1.84	1.42	ns
Proportion of wives who did not attend school	0.09		0.07		ns
Proportion of husbands who did not attend school	0.17		0.10		**
Proportion of wives who completed primary school	0.05		0.05		ns
Proportion of husbands who completed primary school	0.27		0.23		ns
Proportion of wives who completed secondary school	0.35		0.3		ns
Proportion of husbands who completed secondary school	0.14		0.18		ns

Notes: SD is standard deviation. The last column indicates whether mean differences between adopters and non-adopters are significantly different from zero with ** indicating a level of statistical significance of $p < 0.05$. ns indicates that means are not statistically different.

adopters. Furthermore, women from adopter households stated to be significantly less involved in decisions regarding the use of livestock income for all activities compared to women from non-adopter households.

4.3. Correlates of fodder chopper use

Results of recent meta-analyses reiterated that the adoption of agricultural technologies positively correlates with farmer education, household and land size, land tenure, access to credit and extension services, as well as membership in agricultural organizations (Ruzzante et al., 2021; Schulz and Börner, 2023). However, the relative importance of adoption determinants varied by technology, cultural context and

Table 6
Wife and husband engagement in meat, milk, and fodder production, participation in related decision making, and influence in decisions over the use of income.

	Husband interviews			Wife interviews		
	(I) Non-adopters n = 175	(II) Adopters n = 198	(I) vs. (II)	(III) Non-adopters n = 175	(IV) Adopters n = 198	(III) vs. (IV)
	Time allocation					
For fodder chopping (minutes)	46.80 (39.2)	42.27 (34.46)	ns	25.71 (18.11)	20.91 (21.57)	-20.6 %***
For all livestock activities (minutes)	187.03 (108.68)	200.15 (118.31)	ns	186.51 (96.21)	153.64 (90.81)	-19.3 %***
Meat production						
Respondent is engaged in activity	0.82	0.89	+8.2 %**	0.74	0.74	ns
Respondent is main decision-maker	0.41	0.54	+27.4 %***	0.02	0.02	ns
Influence most income decisions	0.37	0.52	+37.7 %***	0.15	0.07	-72.7 %***
Milk production						
Respondent engaged in activity	0.66	0.81	+20.4 %***	0.83	0.82	ns
Respondent is main decision-maker	0.21	0.37	+55.2 %***	0.21	0.25	ns
Influence most income decisions	0.25	0.42	+50.7 %***	0.45	0.35	-12.5 %*
Fodder production [#]						
Respondent engaged in activity	0.76	0.88	+14.6 %***	0.71	0.52	-15.4 %***
Respondent is main decision-maker	0.53	0.66	+21.8 %**	0.01	0.01	ns
Influence most income decisions	0.30	0.38	ns	0.13	0.06	-36.8 %**

Notes: Figures are means with standard deviation in parenthesis. # Number of fodder producers n = 140 for adopters and n = 198 for non-adopters. The respondent is engaged in the activity if the respondent supplies labor; the respondent is the main decision-maker if most or all decisions are taken by the respondent; the respondent has influence in most income decisions if the respondent can decide on how the income from the activity is used by the household. Data presented is obtained from either the wives' (columns (III) and (IV)) or husbands' (columns (I) and (II)) interviews by status of mechanized fodder chopper adoption. Columns '(I) vs. (II)' and '(III) vs. (IV)' indicate whether mean differences between adopters and non-adopters are significantly different from zero with ***, **, and * indicating levels of statistical significance at the $p < 0.01$, $p < 0.05$, and $p < 0.10$, respectively. ns indicates that means are not statistically different.

geography (Ruzzante et al., 2021). In the case of small-scale farm machinery, we expect human capital, available family labour, land, and livestock endowments, as well as geographical location-as a proxy of household connectivity to markets, services, and information-to influence household adoption behaviour (Aryal et al., 2020; Mottaleb et al., 2016).

Table 7 presents estimation results for the correlates of the adoption of mechanized fodder choppers. Our results indicate that the probability of adopting mechanized fodder choppers increased with husband's education level, an increase in size of the homestead land, and a larger livestock herd. Accordingly, the probability of observing adoption increased by 12 percentage points if the husband completed secondary school, by 0.06 percentage points for every 1 % increase of the size of the homestead land, and by 0.18 percentage points for every 1 % of increase in the total herd size (Table 7). These are common findings in the empirical literature on adoption determinants of farm machinery. For instance, Aryal et al. (2021) found the number of livestock units owned to be positively correlated to the adoption of agricultural mechanization on smallholder farmers in South Asia. Schulz and Börner (2023) concluded that livestock herd size and education levels tended to have positive effects on use of agricultural technologies.

4.4. Implications for time allocation

Mechanized fodder choppers have the potential to significantly reduce the time allocated to fodder preparation. Adopters may reallocate saved time to other livestock, on-farm or off-farm activities. In our sample, we find that adopter households spent more time cleaning their animals and stable, milking, purchasing, and transporting fodder (Fig. 1). Adopting households used less time on fodder harvesting, fodder preparation, livestock feeding and taking livestock for grazing to the fields compared to non-adopters. Notably, the largest reduction was observed for fodder harvesting and not for fodder processing. Since non-adopters do not grow more food on their farms, disparities in time allocation could be related to variations in harvesting practices, i.e., mechanized chopping may require less processing of fodder at harvest.

In terms of intra-household gendered time allocation, we observed that adoption of mechanized fodder choppers did not change who spent more time on an activity between wife and husband (except for milking

Table 7
Correlates of the adoption of mechanized fodder choppers.

	Marginal effects
Age of wife (years)	-1.75E-3 (4.15E-3)
Age of husband (years)	2.17E-4 (4.10E-3)
Wife completed secondary school (1 = yes)	-0.06 (0.04)
Husband completed secondary school (1 = yes)	0.13** (0.06)
Adult household members (no.)	1.05E-3 (0.01)
Size of homestead land (decimals, natural logarithm) [#]	0.06*** (0.02)
Total size of farmland (decimals, natural logarithm) [#]	7.03E-3 (0.01)
Herd size large livestock (no., natural logarithm)	0.18*** (0.05)
Importance of livestock raising for household income (scale 0-2) ^{##}	-0.03 (0.06)
No. observations	373
Pseudo R ²	0.12
Log pseudo likelihood	-225.82
Wald χ^2	124.49
Prob > χ^2	0.00

Notes: Estimates are based on a probit model. The dependent variable is binary and indicated whether a household adopted mechanized fodder choppers. Standard errors in parentheses are robust and clustered at the district level. **, *** indicate results are statistically different from zero at the $p < 0.05$, and $p < 0.01$ level, respectively. [#] 1 Decimal = 0.004047 ha or 40.47 m². ^{##} Self-reported importance of livestock raising in household income with 0 = not important, 1 = as important as other income sources, 2 = most important income source.

animals). Most notably, gendered time allocation for fodder chopping did not change with adoption of mechanized fodder choppers within surveyed households (Fig. 2). Compared to men, women were found to spend less time on fodder preparation irrespective of the use of mechanized choppers. The adoption of mechanized fodder choppers decreased women’s time use relative to men’s for harvesting, milking animals, livestock feeding and cleaning their animals and stable.

When accounting for potential confounders that may affect time allocation to livestock production, such as herd size, estimation results based on IPWRA suggest that the adoption of mechanized fodder choppers is not associated with households’, husbands’ or wives’ total time allocation to fodder chopping, and only a marginal reduction of wives’ time for fodder processing per tropical livestock unit (TLU) (Table 8). However, when disaggregating the sample by size of livestock herds, we found significant time reductions for fodder chopping among households with the smallest herds (Table S4). Given the moderate

average reductions in time use, the adoption of mechanized fodder choppers may be motivated by expected gains in livestock productivity due to improved feed quality, anticipated increases in profits, and household income (Fischer et al., 2018).

The adoption of mechanized fodder choppers may have implications on time use for other livestock related activities. Table 9 shows the IPWRA based correlations between the adoption of mechanized fodder choppers and total time used for all livestock related activities, as well as time use per TLU. The estimates show that the adoption of mechanized fodder choppers was associated with a significant reduction in women’s time use for all livestock raising activities (about 35 min). Estimates remain robust when using alternative regression models (Table S5). When disaggregating the sample by herd size, women’s time savings were detected among households with small and medium-sized herds (Table S6).

Reductions in women’s workload are also reported by several studies on implications of the use of farm machinery. For example, Theis et al. (2019) found that reaper-harvester use in Bangladesh led to time savings for women. In India, Gartaula et al. (2020) reported decreased workload from adopting direct-seeded rice technologies, while Afridi et al. (2023) observed reduced farm labor due to mechanized soil tilling in India. Similarly, Farnworth et al. (2022) found that women farmers benefited from reduced workload using farm machinery.

Whether reductions in time use for livestock production have positive implications for women depends on the utilization of the additional time. Employing the IPWRA with time use for different activities not related to livestock production as dependent variables (Table 10), we observed that women in adopter households spent more time resting which can support individual wellbeing (Kim et al., 2015). The time allocation effects on women’s engagement in off-farm employment are small and only weakly significant. Also Afridi et al. (2023) and Farnworth et al. (2022) report that women’s time savings related to farm machinery did not correlate with increased agricultural labor opportunities or time engaged in off-farm employment in India. Husbands reduced their engagement in domestic and care work, from a low initial level, and in farm work unrelated to livestock production. Similar to women, they spent more time sleeping and in off-farm employment, with both changes being marginally significant.

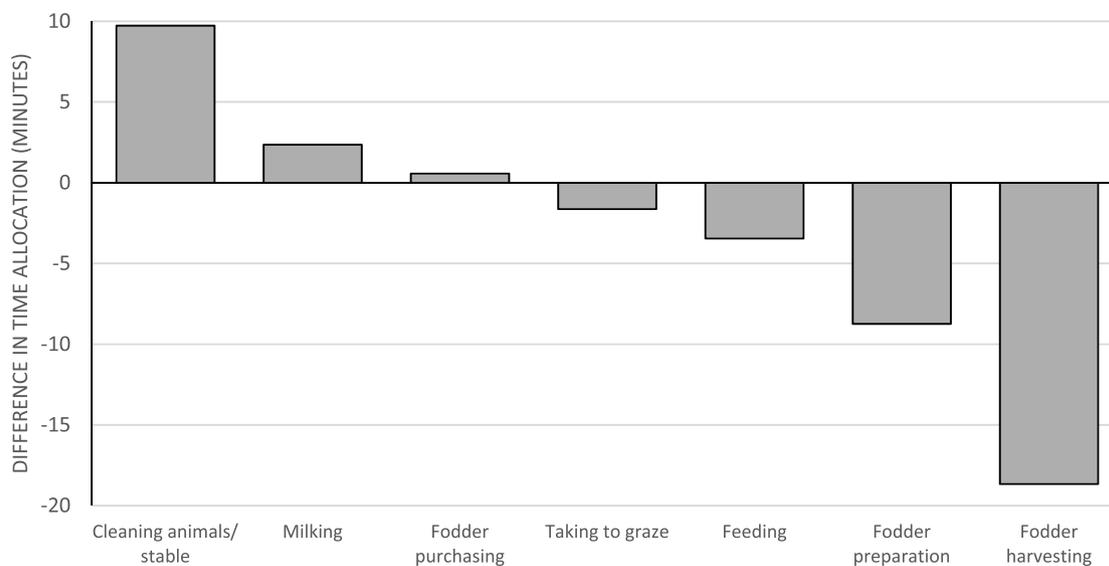


Fig. 1. Differences in households’ time allocation for livestock raising activities between fodder chopper adopters and non-adopters. Notes: Bars indicate the differences in total minutes spent by households on the respective activity between fodder chopper adopters and non-adopters. Positive (negative) values indicate households adopting mechanized fodder choppers spend more (less) time on respective activity.

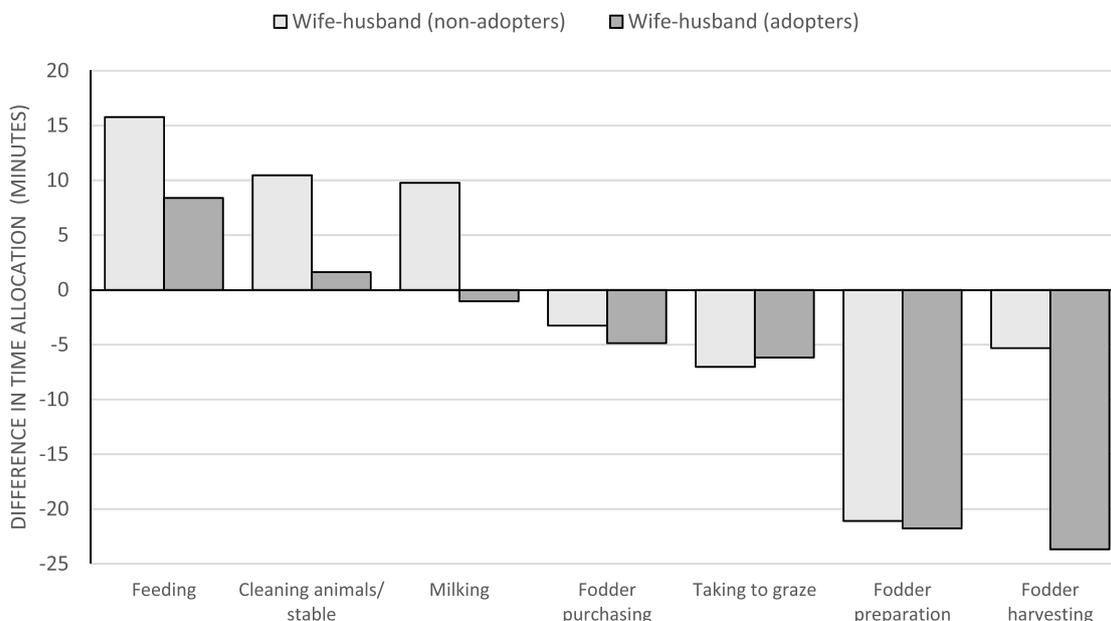


Fig. 2. Differences in time allocation between wife and husband for adopters and non-adopters of mechanized fodder choppers. Notes: Bars indicate differences in total minutes spent by wives and husbands from the same household on the respective activity. Positive (or negative) values indicate that wives spend more (less) time on the activity compared to their husbands.

Table 8
Correlation between the adoption of mechanized fodder choppers and time allocation to fodder chopping.

	(1)		(2)		(3)	
	Household		Husband		Wife	
	ATET	PMeans	ATET	PMeans	ATET	PMeans
Total time allocation to fodder processing (minutes)	-6.56 (6.26)	69.75*** (5.55)	-3.05 (5.11)	45.33*** (4.63)	-3.51 (2.63)	24.42*** (2.10)
Time allocation per TLU (minutes)	-3.29 (2.33)	15.21*** (2.39)	-1.63 (1.67)	9.11*** (1.68)	-1.78* (1.01)	6.57*** (1.00)

Notes: No. observations for all models is 368. ATET is the average treatment effect on the treated, PMeans is the mean potential outcome for non-adopters. Treatment effect estimates are based on Inverse Probability Weighted Regression Adjustment (IPWRA). Standard errors in parentheses are robust. *p < 0.1, **p < 0.05, ***p < 0.01. Outcome variables are household, husband, and wife total time allocation for fodder chopping and time allocation per tropical livestock unit (TLU). Control variables in the treatment equation are the same as in Table 7. Control variables in the outcome equation are the number of large livestock owned by the household, the number of adult household members, the share of fodder produced on own farm and household location fixed effects at the division level. Full model results (Table S3), summary statistics for covariate balancing (Table S2) and common support (Fig. S1) are contained in the supplementary materials.

Table 9
Correlates between the adoption of mechanized fodder choppers and time allocation for all livestock raising activities.

	(1)		(2)		(3)	
	Household		Husband		Wife	
	ATET	PMeans	ATET	PMeans	ATET	PMeans
Total time allocation to all livestock activities (minutes)	-38.55* (21.28)	392.34*** (18.88)	-3.75 (17.83)	203.90*** (16.18)	-34.80*** (13.62)	188.44*** (12.11)
Time allocation per TLU (minutes)	-19.38* (10.78)	89.95*** (11.34)	-5.03 (5.65)	42.18*** (5.78)	-14.35** (6.42)	47.66*** (6.63)

Notes: No. of observations for all models is 368. ATET is the average treatment effect on the treated, PMeans is the mean potential outcome for non-adopters. Treatment effect estimates are based on Inverse Probability Weighted Regression Adjustment (IPWRA). Standard errors in parentheses are robust. *p < 0.1, **p < 0.05, ***p < 0.01. Outcome variables are household, husband, and wife total time allocation to all livestock raising activities, i.e., fodder preparation, fodder harvesting, cleaning animals and stable, livestock feeding, milking, taking animals to graze, purchase and transport fodder to homestead and time allocation to all activities per tropical livestock unit (TLU). Control variables in the treatment equation are the same as in Table 7. Control variables in the outcome equation are the same as in Table 8. 5 observations were dropped because they were outside the common region of support.

4.5. Intra household decision-making dynamics gendered control over livestock-based income

While more resting time may enhance women’s wellbeing, the implications on gendered decision-making dynamics and control over income from livestock production are less clear. Our dataset includes

wives’ and husbands’ self-assessment of their individual roles in decision-making in livestock management and in use of income from meat, milk, and fodder production. We estimated the correlations between fodder chopper use and women’s role in decision-making in livestock management, as well as women’s influence in the use of income from meat, milk, and fodder production. Our analysis shows that

Table 10
Correlates between the adoption of mechanized fodder choppers and wives' and husbands' time allocation to activities other than livestock raising (in minutes).

	Effects on wives' time allocation		Effects on husbands' time allocation	
	ATET	POmeans	ATET	POmeans
Leisure	-5.17 (10.15)	115.17*** (9.09)	2.74 (8.77)	102.72*** (8.07)
Domestic and care work	22.54 (16.45)	333.82*** (14.53)	-28.72*** (10.75)	86.00*** (10.46)
Farm work (non-livestock)	-0.77 (2.79)	7.59*** (2.82)	-53.44* (30.32)	154.04*** (28.91)
Employed or self employed	9.31* (15.68)	17.36*** (14.23)	55.18* (30.97)	161.34*** (27.84)
Religious activities	-6.33 (9.38)	119.81*** (8.76)	9.75 (8.17)	71.92*** (7.60)
Sleeping	29.64** (11.98)	473.08*** (10.04)	20.76* (12.47)	465.00*** (11.42)

Notes: The number of observations for all models is 368. ATET is the average treatment effect on the treated, POmeans is the mean potential outcome for non-adopters. Treatment effect estimates are based on Inverse Probability Weighted Regression Adjustment (IPWRA). Standard errors in parentheses are robust. *p < 0.1, **p < 0.05, ***p < 0.01. Dependent variables indicate wives' or husbands' time allocation to different activities during the last 24 h preceding the interview in minutes. Control variables in the treatment equation are the same as in the model in Table 7. Control variables in the outcome equation are the same as in Table 8. 5 observations were dropped because they were outside the common region of support.

mechanized fodder chopper use was associated with husbands' claiming more influence over decisions on the use of income from meat and milk production (Table 11). To test the robustness of the estimates to hidden bias, we estimated additional propensity score models and calculated Rosenbaum bounds (Table S8). Rosenbaum bounds indicate how large differences in unobserved factors that determine the decision to adopt mechanized fodder choppers would need to be to render treatment effects insignificant. Estimated bounds were 1.5 and 1.75 for the effects of mechanized fodder chopper use on husbands' influence over income from meat and milk production, respectively. This implies that farmers who were matched on observed covariates would need to differ in unobserved covariates by a factor of 1.5 (50 %) and 1.75 (75 %) to undermine the statistical significance of the estimated treatment effects.

Table 11
Correlates between the adoption of mechanized fodder choppers and husbands' or wives' influence on the use of income from livestock raising activities.

	(I)		(II)	
	Wife influence over use of income		Husband influence over use of income	
	ATET	POmeans	ATET	POmeans
Meat production	-0.04 (0.05)	0.10** (0.05)	0.25*** (0.07)	0.26*** (0.06)
Milk production	0.05 (0.08)	0.30*** (0.07)	0.17** (0.07)	0.25*** (0.06)
Fodder production	0.01 (0.04)	0.04 (0.04)	0.03 (0.08)	0.36*** (0.07)

Notes: The number of observations for all models is 368. ATET is the average treatment effect on the treated, POmeans is the mean potential outcome for non-adopters. Treatment effect estimates are based on Inverse Probability Weighted Regression Adjustment (IPWRA). Standard errors in parentheses are robust. *p < 0.1, **p < 0.05, ***p < 0.01. Dependent variables indicate wives' or husbands' influence over the use of income from different livestock production activities. Control variables in the treatment equation are the same as in the model in Table 7. Control variables in the outcome equation are the same as in Table 8. 5 observations were dropped because they were outside the common region of support. Complementary estimations using propensity score matching and Rosenbaum bound analysis show that estimates are robust to hidden bias.

We also found an increased husband influence over income use decisions irrespective of herd size (Table S7).

These changes in intra-household decision-making may contest women's agency in livestock production, a tendency reported in studies on the use of farm machinery in South Asia. Farnworth et al. (2020) found that the use of mechanized mung bean harvesters in Myanmar and Bangladesh weakened economic and personal empowerment of landless women workers. Similarly, Fischer et al. (2018) reported that mechanized fodder chopper adoption in Tanzania could increase disputes over intra-household labor division and income allocation. Theis et al. (2019), in contrast, noted increased women's involvement in intra-household decisions with the use of reaper harvester in Bangladesh.

5. Summary and conclusion

In this paper, we analyzed the associations between the adoption of mechanized fodder choppers and women's empowerment in livestock producing households in Bangladesh. Focusing on gendered time use, gender roles in decision-making, and influence in use of livestock income, our findings indicate that the adoption of mechanized fodder choppers was associated with men claiming more influence in management decisions and income use, in a context in which most decision-making in livestock production was already largely male dominated. In contrast, women's engagement in decision-making and influence over income use were not positively associated with the adoption of mechanized fodder choppers. The adoption of mechanized fodder choppers was, however, associated with reduced women's workload and increased resting time, which is likely to have positive implications for women's wellbeing and health.

Given the cross-sectional and observational design of the study, the reported relationships should not be interpreted as causal. Nonetheless, the results provide important insights into the complex relationships between the use of farm machinery and women's empowerment. For instance, the adoption of farm machinery may reduce the demand for agricultural labor and negatively affect seasonal income opportunities for landless, resource poor and women farmers. Harnessing the full potential of agricultural mechanization while minimizing its trade-offs requires careful assessment of both intended and unintended outcomes for all men and women farmers.

In this context, development initiatives and policies may require safeguards which ensure that women can effectively access and benefit from farm machinery. These safeguards should not only address technical aspects, e.g., gender adequate machinery design, access to information and extension services, but should also consider how social norms and institutions influence women's use of farm machinery and how they shape potential outcomes. This can contribute to minimizing the risk that interventions reinforce existing inequalities and can enhance the provision of targeted support to address barriers women face in utilizing and profiting from farm machinery.

CRedit authorship contribution statement

Michael Euler: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Stephanie Cheesman:** Writing – review & editing, Data curation. **Farah Keya:** Writing – review & editing, Data curation. **Santiago López-Ridaura:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization. **Mizanur Rahman:** Writing – review & editing, Data curation. **Timothy J. Krupnik:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence

the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jrurstud.2025.103839>.

Data availability

Data will be made available on request.

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