Performance evaluation of portable milking machine on machine economy, milk yield, milking time, and milk constituents of Nepalese Cattle

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Abstract: Hand milking, a most common practice for majority of the farm households is a labor and time intensive process in Nepal. Effect of milking machine on milk yield, milking time, milking rate and milk composition, and economical aspects of machine use was investigated on cow milking applying portable two cluster bucket type milking machine. Three treatments were investigated as follows: hand milking, machine milking (M1) @330 mmHg vacuum pressure and machine milking (M2) @290 mmHg vacuum pressure. The obtained daily milk yield for hand milking (7.58 ± 1.28 kg) was 7.3% and 2.4% higher than machine milking M1 (7.02 ± 1.89 kg), and M2 (7.40 ± 1.69 kg), respectively. The milk yield did not differ statistically between hand and machine milking methods ($p > 0.05$). Milking machine significantly shortened the cow milking time from 11.91 minutes (hand milking) to 5.38 minutes (M1) and 4.98 minutes (M2) respectively. Similarly, milk flow rate for hand milking (0.32 kg min^{-1}) was 52.9% (0.68 kg min^{-1}) and 57.3% (0.75 kg min^{-1}) lower than M1 and M2, respectively. There were significant differences in milking time and milk flow rate between machine milking and hand milking ($p<0.05$). Results indicated that there was no any difference between milking methods in the incidence of milk composition ($p>0.05$). The use of a milking machine saves more than one half the labor required for milking a herd of 17 cows. Cost saving achieved by our result were 39.47%-58.98% for machine milking depending on the number of cluster. Therefore, we concluded that greater saving in labor and cost can be occurred in larger and higher producing herds by the use of two or more cluster milking machine. Importantly, an economical aspect of the milking machine use is basically proportional to the size of the herd.

Keywords: cow, economical aspects, milk yield, milk composition, milking machine, performance evaluation

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1 Introduction

Livestock is one of the key sectors in the agriculture based economy of Nepal. Nepalese statistics shows the agriculture contribution of about 26.8% to the National GDP of which around 13% of the contribution comes from the livestock sector (MoAD, 2017).The dairy sector contributes about 8% in GDP and two third in livestock sub-sector (ADS, 2013). Livestock statistics of FY

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2015/16 shows a total of 7.30 million cattle and 5.16 million buffaloes in Nepal contributing to the annual milk production of 1.85 million MT (0.64 million MT from cows and 1.21 million MT from buffalos) (CBS, 2017; NCRP, 2017). In Nepal, out of total 3.35 million households about 2.28 million house hold raise cattle and 1.6 million household raise buffalo (CBS, 2017).

Cattle are the main source of milk production, animal traction and manure in Nepal. Milk production in Nepal is still carried out under the traditional production system, in the mixed farming system, with small non-commercial holdings (Timsina, 2010). Currently, numbers of commercial farms are also growing. Hand milking, a most common practice for majority of the farm households in Nepal, is considered to be one of the most labour intensive and time consuming practices. Manual milker may suffer stiff shoulder, pain in knee joints and backbone and weakness after milking more number of cows in a day (Gadekar et al., 2017). Poor milk quality is being one of the persistent problems of Nepal which causes loss of income along the milk chain. The basic reasons are attributable primarily to the lack of hygiene, contamination during hand milking and inadequate sanitation at the production level, since major milk producers are small, marginal and poor, living at the subsistence level. There are issues of milk safety and quality in Nepal as less than fifty percent farmers (43.75%) practiced hand washing with soap before milking and rest (56.25%) washed their hands by common water only (Bastola and Dainik, 2012).

Production cost of milk in Nepal is generally 10 to 20 percent higher as compared to India which compelled low profit margin for Nepalese farmers (Timsina, 2010). Labor cost associated with the milking process is the major cost for milk production. As the farmers cost of milk production is increasing due to increased labour wages rate and labour scarcity (migration of youth for off-farm jobs within or outside countries), use of machine could be one of the beneficial and efficient options for reducing the production cost and improving labour efficiency. Farmers will have enough spare time saved from the milking process and associated tasks thus labor can be used for supervision of animal feeding and other livestock work. It is also possible to produce high quality milk without any injuries to the udder by following appropriate milking machine and milking procedures (Chaudhary et al., 2001). Due to these associated benefits, machine milking is currently being attraction of farmers. According to Nepalese agricultural machinery import statistics of Department of Customs, around 647 numbers of milking machines imported from foreign countries in FY 2018/19 (MOF, 2019).

Higher capacity mechanized milking parlor is not appropriate for small and medium scale farmers. The bucket type portable milking machine could be one affordable option for them. Previous studies have reported the effects of machine milking on milk production. For instance, Aslam et al. (2014) performed machine and hand milking on cow and reported a 12% increase in milk production and a 18% decrease in labor, and improve dairy cow welfare (Aslam et al., 2014). Likewise, Khan (2008) investigated the performance of bucket type milking machine on milk yield of water buffaloes. From his results, the vacuum level 46-48 kPa and 44-46 kPa gave maximum milk yield (0.807 and 1.086 liters per minute) for single and double clusters, respectively. However, there is no comparison with hand milking on machine economy, milking time and milk composition on his study. In a similar study, Matthews et al. (2017) performed machine milking to investigate effect on milk yield and labour saving. From their findings, milking method had no significant effect on milk yield but a saving of 52% in labour was occurred. From our literature survey, we found no studies addressing milking machine use economy, phenomena of saving in labour and milking characteristics of Nepalese cattle.

To address this gap, this study evaluated milk yield, milking time, milk flow rate, and milk constituents to examine the effect of milking methods (hand and machine milking) in Holisten and jersey cows. Furthermore, preliminary economic viability evaluations in terms of labour and cost saving between milking methods were also integrated in this study.

2 Materials and methods

2.1 Experimental site description

Field experimental work was performed in National Cattle Research Program (NCRP), Nepal Agricultural Research Council (NARC), Rampur, Chitwan, Nepal during month of July, 2019 and rest of work was performed in Agricultural Engineering Division, NARC, Khumaltar, Lalitpur. Geographically, NCRP is located in the central region, province 3 of Nepal having latitude, longitude and average mean sea level of 27^o40’N, 84^o35’E and 187 masl., respectively (NCRP, 2017). It is 11 km southwest from the Narayangarh city and 157 km farm from Kathmandu, a capital city of Nepal. NCRP has climate of sub-tropic. Maximum and minimum temperature in the experimental site for the month of July are $36^oC \pm 1.71^oC$ and minimum is $27^oC \pm 1.10^oC$ (n=20). NCRP is a commodity program of NARC, undertaking research on production and productivity of cattle emphasizing quality milk production, product diversification and overall management of economic cattle production. During 2016/17, a total of 100,995 liters milk (with average daily milk production of around 300 liters) was produced (NCRP, 2017).

2.2 Milking cows and feeding pattern

27 lactating cows were selected for the experiment. Jersey (25 numbers) and Holstein Friesian (HF; 2 numbers) cattle were the types of cow varieties used in milking experiment. Cattle were kept in Stanchion barn (conventional dairy barn) which is east west orientated and has aluminum sheet roofing. There is also fan cooling system and water sprinkle system in the barn for heat stress management. In dairy housing barn, cattle were kept following both double row and tail to tail system. Tail to tail system has associated benefit of easiness in cleaning and milking of cattle, easy supervision and possibility of individual care, labour friendly, adequate fresh air entry from outside and easy handling of milking machine. Each animal were ear tagged with number for identification of animal. Fresh drinking waters were given to the animals throughout the experimental period. Machine milking and hand milking was performed separately. Milking was performed in dairy shed having concrete floors and rubber mats. Water and silage were provided in respective trough. The cattle of different age group were provided with appropriate ratio of roughage and concentrate according to their need for the improvement of good health as well as high production of farm animal. Feeding to animal was done on the basis of body weight and milk production by NCRP staff as per their regular schedule. Two to four kilogram for maintenance ration and one kilogram of concentrate was provided at the rate of two kilogram of milk production above the maintenance requirement.

During whole experiment duration, consistent routine was followed from one milking to the next. Prior to each experimental work, parlour was cleaned with normal water, and cows and its udder were washed with clean water and dried with clean piece of towel (cloth). As experimental work was performed in summer season, moderate warmed clean water is used for cleaning teats. Post teat dipping solution (iodine) was applied immediately in teat after removal of milking cluster. Dipping solution was prepared by mixing povidone iodine and glycerol (9:1) and stored in dip container. Water and fresh feed were supplied to cows after milking. Milk production and milking time was recorded daily in two shifts (morning and evening) and milk composition was recorded for both manual and machine milking.

2.3 Features of milking machine

Bucket type milking machine is usually suitable for small and medium scale cattle farmers. Thus considering this fact, two portable bucket milking machines were used in experiment (Figure 1 and Figure 2). Machines were operated by 1 hp electric motor. Both machines can milk 2 cows at same time which can minimize time, labour and increase the production rate. Machine 1 (M1) has working vacuum pressure of 330 mmHg (44 kPa) and that of machine 2 (M2) is 290 mmHg (39 kPa) in our study. From the previous different studies by researcher, the recommended average claw vacuum for rapid, complete milk removal with minimal physical harm and highest milk quality is from 32 to 42 kPa in the claw during peak milk flow for the majority of cows (Khan, 2008; Reinemann et al., 2005). Lower milking vacuum extends machine on time (increases frequency of liner slips, decreases milk flow rate and may reduce milk yields whereas higher milking vacuum level can lead to teat tissue congestion, poor teat skin condition and incomplete milk out (Reinemann et al., 2005).The pulsation ratio of machine was 60:40. Average pulsation rate of M1 and M2 were 62 and 58 cycle per minute, respectively. M1 and M2 were used for milking 10 and 17 cows, respectively during machine milking experiment for two days (first and second day). For manual milking observation, 6 cows were randomly selected among 27 cows and manually milked in third and fourth day. Attachment of teat cups was performed on quarter level with the attachment order of right rear, left rear, right front, and left front teat as described by Krawczel et al. (2017). The milking machine and its interior milk contact surfaces were carefully washed with warm water before and after milking operation.

Major features along with parts of milking machine are shown in Figure 1 and Table 1 which includes a claw, four teat cups (shell and silicon rubber liners), long milk tube, long pulsation tube, pulsator, vacuum pump, tank, receiver and electric motor (Lazovic, 2016)

Teat cup shell and teat cup liner: The milking cluster consists of four teat cups along with claw, and pulsation tube. Each teat cup has an outer shell, a rubber liner, a short milk tube and a short pulsation tube (Lazovic, 2016). Teat cup shells are made of stainless steel. These components allow milk to be removed from the teat.

Claws: claw provide connection of short pulse tubes and short milk tubes from the teat cups with the long pulse tube and long milk tube. It should be of adequate size to avoid flooding.

Vacuum pump: The function of vacuum pump is to remove air from a closed system and create a partial vacuum (Lazovic, 2016).

Pulsator: pulsator is used to massage the teat at regular intervals and maintain blood circulation to avoid teat congestion (Jones, 2009). Pulsator open and close the teat once each second by connecting the pulsation chamber of the teat cup to vacuum or atmosphere. The annular space between the shell and liner is called the pulse chamber.

Inceptor: It prevents liquid and dust being sucked into the vacuum pump through vacuum line.

Vacuum regulator: a steady vacuum is maintained by regulator in spite of varying air usage.

Vacuum gauge*:* It indicates vacuum pressure of the system that helps to monitor machine performance and defects.

Milking cluster assembly: single milking cluster consists of four teat cup assemblies (each having a shell and a rubber liner), a claw, a long tube and long pulse tube.

Oil cup: To lubricates vacuum pump.

Electric motor: vacuum pump is operated by electric motor

Frame*:* machine is fitted on the portable frame having wheels with other equipment i.e. vacuum pump, bucket, receiver, electric motor etc.

2.4 Working principle of milking machine

Bucket type milking machine system consists of four basic components, a) a vacuum system, b) pulsators that alter the vacuum level around the teat, c) milking units or cluster made of four teat cups with liners connected to a claw and d) milk collection tank. Upon attaching the teat cup, milking machines extract milk from the dairy cow by applying a partial vacuum to the teat creating a pressure difference that results in opening of the streak canal and milk flowing out from the teat cistern through a pipe to a receiving container (Gleeson et al., 2004). Since constant application of vacuum on the teat is painful it is countered by application of pulsation. Asides from relieving pain, the pressure applied during the collapse of the liner massages the teat that relieves the pain and also prevents congestion of blood and lymph in the teat (Khan, 2008; Lazovic, 2016).

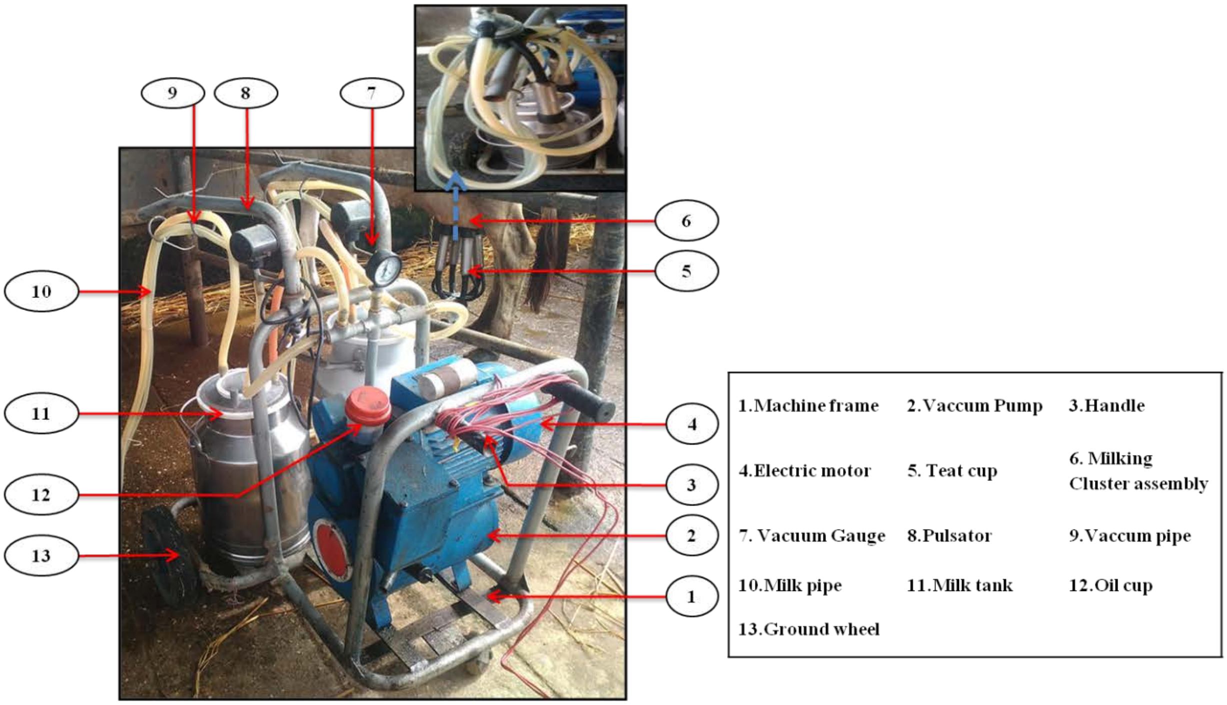

Figure 1 Photographic view of portable bucket milking machine showing different parts used in this study

Table 1 Features of double bucket milking machine used in our study

Parameters	Specification
Pulsation rate (cycle min^{-1})	58-62 times min^{-1}
Pulsation ratio	60/40
Working vacuum pressure (mmHg)	270-330
Power operated	electric motor, 1 HP
RPM	1440
Voltage	220 V, 50 Hz
Milking clusters	2 set
Milking bucket	2 nos. @ 20 L each , stainless steel
Milk hose and vacuum hose	silicon food grade

2.5 Experimental data collection and statistical analysis

Both manual and machine milking was performed in morning (6 am) and evening (4 pm) time daily (Figure 2). Milking time and milk yield were noted daily for each individual cow. Electric weighing balance was used to record the milk yield in kg. Similarly, milking time was noted by using stop watch. Number of times the units were adjusted by operators because of slipping or fall-off was noted down to see the frequency of slipping or falling teat cups. Samples from hand milking and machine are collected in air tight bottles for milk composition analysis. Lacto Scan Milk Analyzer was used to analyze the composition of collected milk samples in NCRP laboratory. Briefly, milk sample bottles were homogenously mixed through hand shaking to avoid any air enclosure in the milk. Then 20 ml samples were taken in the sample tube and put in the sample holder one at a time with the analyzer in the recess position. After then starting button was pressed to activate the analyzer. Immediately the analyzer sucks the milk, makes the measurements, and returns the milk in the sample tube and displays the measured values of specified parameters in the digital monitor. Milk composition parameters determined by analyzer were fat (%), protein (%), Solid Non Fat (SNF %), lactose (%), milk density and temperature. Different experimental parameters i.e., milking time (min), milk yield (kg), milk flow rate (kg min^{-1}), milk temperature (^{0}C), and gross milk composition were considered to evaluate the performance of the machine. Milk flow rate was obtained from milk yield and milking time as following Equation.1 (Reinemann et al., 2005).

$$\text{Milk flow rate (kg min}^{-1}\text{)} = \text{Milk yield (kg) / Time taken to milk (min)} \qquad (1)$$

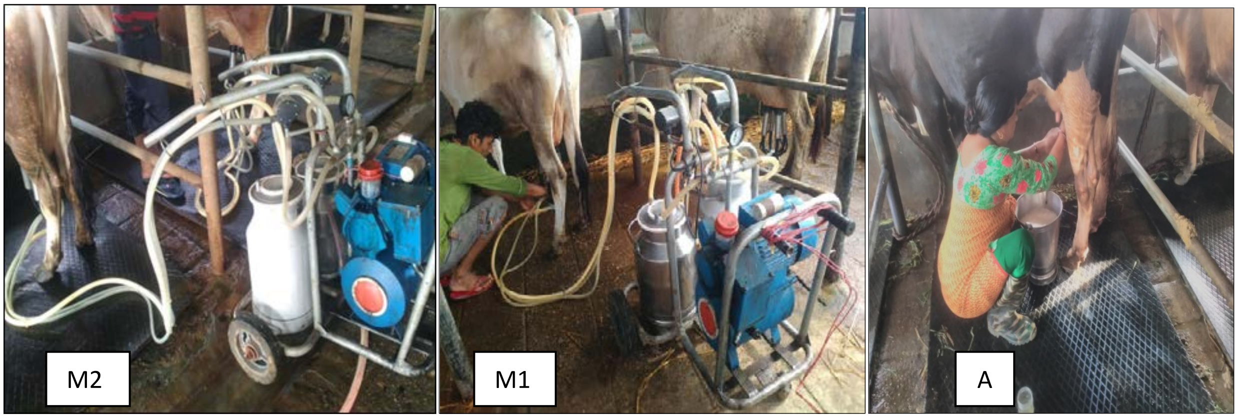

Figure 2 Photographic view of experiment on hand milking (A) and machine milking (M1 and M2)

Machine experiments were performed for two days (morning and evening) and all analyses and measurements are displayed as average values of readings. Descriptive analysis was done to summarize data into averages, standard deviations, and standard error values by statistical tool using MS Excel. Analysis of Variance (One way ANOVA) was used to investigate potential differences in milk yield, milking time and milk flow rate between the treatments. All inferential analysis was done within the 95% level of confidence ($p = 0.05$) using Sigma Plot software version 12.5 (Systat Software Inc, USA).

Our study provides some information about the possibility of broadening the livestock mechanization. We hope this study could help related stakeholder such as farmers, municipalities, rural municipalities, agricultural knowledge center and department of livestock services to be familiar with milking machine and disseminate the technology so that adoption by farmers can be possible. Similarly, preliminary finding of this study can be useful to researcher to compare machine milking in future. However, we considered short term experimental data for the investigation of machine milking phenomena and economical aspects which limits the analysis and findings of our study. Importantly, further investigations using long term machine use is highly recommended in order to obtain data that could be used for short term and long term impacts on udder and tissue health, and long term economical benefits of regular machine use.

3 Results and discussion

The performance analysis of milking machine was carried out on the following parameters:

(a) Frequency of slipping or falling teat cups

(b) Milk production and yield

(c) Milking time

(d) Milk flow rate

(e) Milk composition

(f) Economic aspects of machine milking versus hand milking

3.1 Frequency of slipping or falling teat cups

The cluster weighing 2 kg has light teat cup shells and stainless steel claw piece. According to Jones et al. (2009), a problem exists if more than 10 slips or fall-offs per 100 cow-milking require correction by the milker. During our milking experiment, this kind of problem did not occur. During whole experimental period we noticed three slip from teat. This cluster seemed effective for the smooth and sponge like teats. Low vacuum level, blocked air vents, or restrictions in the short milk tube are the causes of early slippage and fall of teat cups. Slips occurring during late milking can be due to poor cluster alignment or uneven weight distribution in the cluster (Jones, 2009) .

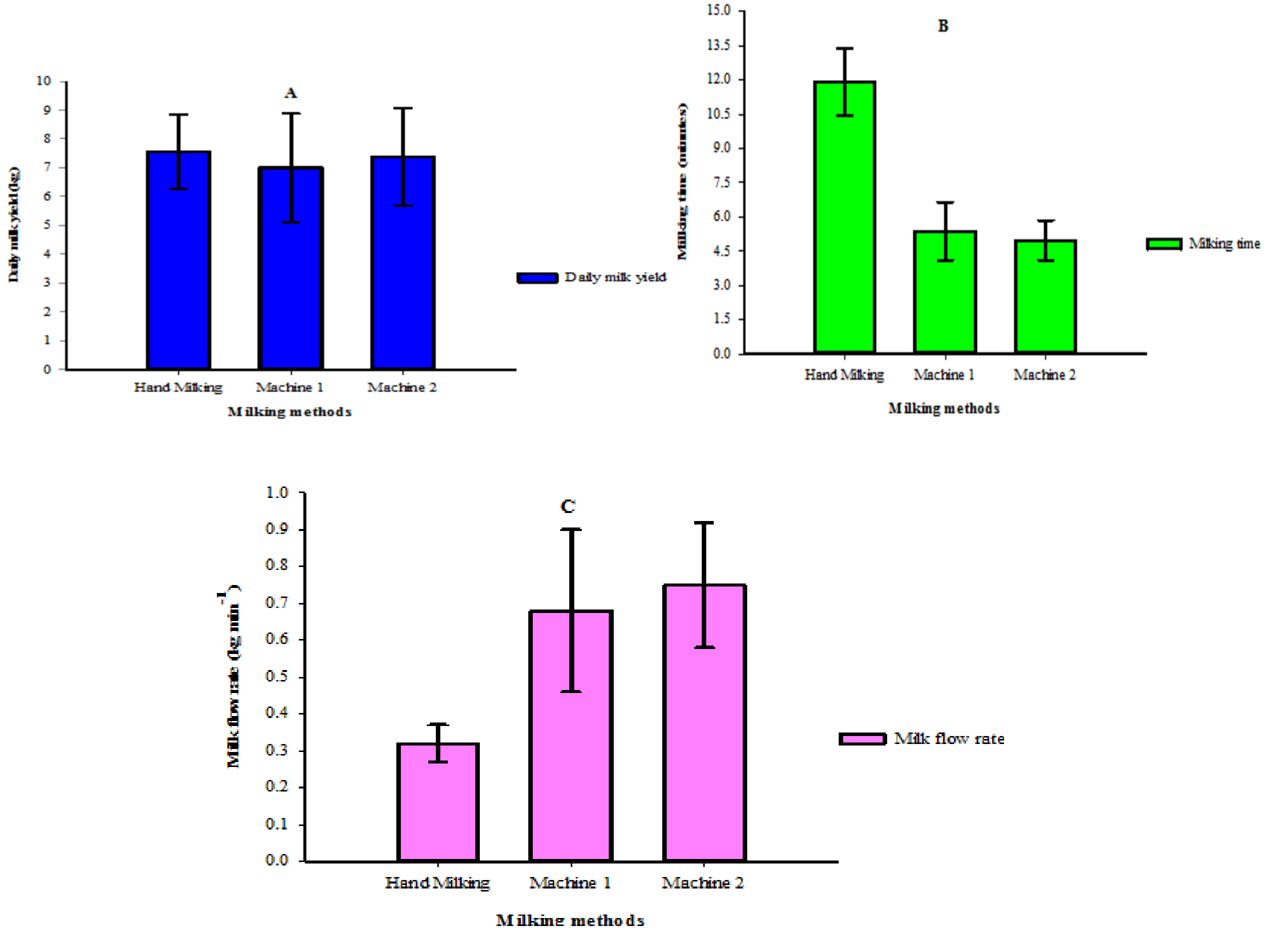

Figure 3 Daily milk yield (A), milking time (B) and milk flow rate (C) of hand and machine milking

3.2 Milk production and yield

Milk yield, daily milk yield, and milking flow rate were presented as average measurements for 2 days. In this study, the average milk yield by hand and machine (M1 and M2) milking were 3.79 ± 0.76, 3.51 ± 1.02, and 3.70 ± 0.91 kg with the range of maximum-minimum values of 5.7-2.0, 8.0-1.86, and 6.8-1.15 kg, respectively. Similarly, average daily milk yield from hand and machine (M1 and M2) milking were 7.58 ± 1.28, 7.02 ± 1.89, and 7.40 ± 1.69 kg (Table 2, Figure 3). From the data, it can be revealed that the achieved daily milk yield for hand milking was 7.3% and 2.4% higher than machine milking M1 and M2, respectively. The method of milking did not influence the daily milk yield. Milk production between hand and machine milking groups was not significantly different ($p > 0.05$, Table 3). Aslam et al. (2014) and Matthews et al. (2017) also reported that there was no significant difference in milk yield of cow between machine and hand milking in their studies. Thus, it can be revealed that the quantity of milk produced is not affected by the use of milking machines in comparison with hand milking.

3.3 Milking time

Milking was performed two times a day (morning and evening). The effect of milking methods on milking time is presented in Figure 3 and Table 2. The average milking time for hand and machine milking (M1 and M2) were 11.91 ± 1.47, 5.38 ± 1.28, and 4.98 ± 0.88 minutes with the range of maximum-minimum values of 13.58-10.25, 7.58-3.56 and 7.0-3.50 minutes, respectively (Table 2).

From the data it can be observed that the milking time for hand milking was 54.8% and 58.1% higher than machine milking M1 and M2, respectively. Milking machine significantly lower ($p < 0.05$) the milking time compared to that of hand milking method (ANOVA Table 3).

3.4 Average milk flow rate

The average milk flow rate is calculated as the total milk yield divided by the total machine on time (Reinemann et al., 2005). Figure 3 and Table 2 showed the effect of three treatments (hand milking, machine milking M1 and M2) on milk flow rate. The average milking flow rate for hand and machine milking (M1 and M2) were 0.32 ± 0.05, 0.68 ± 0.22, and 0.75 ± 0.17 kg min^{-1} with the range of maximum-minimum values of 0.39-0.24, 1.06-0.39, and 1.30- 0.30 kg min^{-1}, respectively (Table 2). The milking flow rate for hand milking was 52.9% and 57.3% lower than machine milking M1 and M2, respectively. There was significant difference in milk flow rate between machine milking and hand milking ($p<0.05$, Table 3).

Table 2 Mean daily milk yield, milking rate and milking time for hand and machine milking

Parameters	Milking method		
	Hand	Machine 1	Machine 2
Average milk yield AM (kg)	4.23±0.79	4.14±1.49	4.66±1.01
Average milk yield PM (kg)	3.36±0.72	2.88±0.56	2.74±0.80
Maximum-minimum milk yield AM(kg)	5.7-3.5	8.0-2.5	6.80-3.10
Maximum-minimum milk yield PM(Kg)	4.1-2.0	5.0-1.86	4.30-1.15
Average daily milk yield (kg)	7.58±1.28	7.02±1.89	7.40±1.69
Milk flow rate AM (kg min^{-1})	0.36±0.06	0.80±0.26	0.94±0.15
Milk flow rate PM (kg min^{-1})	0.28±0.05	0.56±0.17	0.56±0.18
Average milk flow rate (kg min^{-1})	0.32±0.05	0.68±0.22	0.75±0.17
Average milking time AM (min)	11.93±1.80	5.29±1.14	4.94±0.71
Average milking time PM (min)	11.89±1.14	5.48±1.41	5.02±1.05
Average milking time (min)	11.91±1.47	5.38±1.28	4.98±0.88

Note: All values are expressed as means ± standard deviation (n= 6 for hand milking, 10 for M1 and 17 for M2, for 2 days)

Table 3 One way ANOVA depicting differences in daily milk yield, milking time and milk flow rate between machine and hand milking

Daily milk yield					
Source of variation	DF	SS	MS	F	P
Between groups	2	2.404	1.202	0.399	0.673
Residual	57	171.912	3.016		
Total	59	174.317			
Comparison	Diff of Means	t	P	P<0.050	
Comparisons for factor:	milk yield				
Hand milking vs. Machine1	0.567	0.701	0.736	No	
Hand milking vs. Machine2	0.186	0.242	0.81	No	
Machine2 vs. Machine1	0.381	0.778	0.824	No	
Milking time					
Group	N	Median	0.25	0.75	
Hand milking	12	11.783	10.583	13.125	
Machine 1	40	5.083	4.5	6.125	
Machine 2	68	4.917	4.25	5.5	
Comparison	Diff of Ranks	Q	$p<0.05$		
Comparison for factor: milking time					
Hand milking vs Machine 2	63.559	5.836	Yes		
Hand milking vs Machine 1	53.95	4.712	Yes		
Machine 1 vs Machine 2	9.609	1.386	No		
Milk flow rate					
Source of variation	DF	SS	MS	F	P
Between groups	2	1.912	0.956	16.312	<0.001
Residual	117	6.855	0.058		
Total	119	8.767			
Comparison	Diff of Means	t	P	$p<0.050$	
Comparisons for factor: milk flow rate					

Hand milking vs. Machine2	0.433	5.711	<0.001	Yes
Hand milking vs. Machine1	0.362	4.548	<0.001	Yes
Machine2 vs. Machine1	0.0705	1.462	0.147	No

Note: All Pairwise Multiple Comparison Procedures Holm-Sidak method and Dunn's Method (milking time).

3.5 Milk composition

The impacts of hand and machine milking method on milk composition in cows are depicted in Table 4. There was no difference between milking methods in the incidence of milk composition. The machine gave satisfactory milking performance with respect to hand milking. Milk fat is one of the most variable of milk composition. From the Table 4, it can be seen that, the fat, SNF and temperature were lower in machine milking (3.87 ± 0.76, 8.43 ±0.29 and 34.25 ± 0.84) than hand milking (4.53 ± 1.24, 8.62 ± 0.68 and 35.50 ± 0.86), respectively. While density, lactose and protein were slightly higher in machine milking (28.61 ± 0.70, 4.63 ± 0.16 and 3.08 ± 0.1) than hand milking (27.4 ± 0.64, 4.54 ± 0.15, and 3.01 ± 0.10) respectively. The slightly higher milk fat content in hand milking was statistically similar to those milked by machine. The lower fat per cent in machine milking might be due to the large fat globules evacuated with more difficulty and also remain with the residual milk in the udder and variation in milk yield (Chaudhary et al., 2001). Likewise, there is no any significance difference in other milk composition between hand and machine milking (p>0.05). Previous studies on effect of milking methods support our findings. For instance, Aslam et al. (2014), and Filipovic and Kokaj (2009) reported no significant difference in milk composition between hand and machine milking.

Table 4 Milk composition in hand and machine milking

Parameters / Milking method	Fat (%)	Solids Non Fat SNF (%)	Density	Lactose (%)	Protein (%)	Temperature (°C)
Manual milking	4.17±0.63^{a}	8.62±0.68^{b}	27.4±0.64^{c}	4.54±0.15^{d}	3.01±0.10^{e}	35.50±0.86^{f}
Machine milking	3.87±0.76^{a}	8.43±0.29^{b}	28.14±0.36^{c}	4.63±0.16^{d}	3.08±0.10^{e}	34.25±0.84^{f}

Note: All values are expressed as means ± standard deviation (n=5). Same letters in column represents not significantly different at (p < 0.05)

3.6 Economic evaluation of machine milking versus hand milking

3.6.1 Labour efficiency and saving by machine milking compared to hand milking

In order to make rough preliminary economic considerations, we compared the added value related to labour saving in machine milking relative to hand milking. During computation, the achieved milking time of the discussed experiment were extrapolated to daily labour hour and later to weekly labour hour. Average daily production per cow and average milking time were taken by average value of two machines (M1 and M2) during machine milking. Table 5 showed the labour efficiency and labour required to milk cows in a herd (consisting of 17 cows) by manual milking was compared with respect to machine milking. In machine milking, total time included the time for washing, sterilizing and proper cleaning for the machine plus the time taken to milk the cows. We considered one labour for machine milking and one for manual milking. During experiment, the double cluster machine was used to milk two cows at a time. Labour saving calculation was done on the basis of both single and double cluster machine. Similarly, time taken to wash, sterilize and clean the machine and utensils used in machine and hand milking were also considered.

For one cluster and two cluster machines, a labour saving of 52.82% and 72.79%, respectively were achieved by the use of milking machines. From the table, it can be said that hand milking need almost 2.11 and 3.67 hours to milk same quantity as that by single and double cluster machine in one hour. One labour can milk 18.64 kg of milk per hour by hand but he can milk 37.59 and 64.83 kg of milk per hour by single and double cluster machine which is 106.66% and 247.80% higher than hand milking. A previous study by Matthews et al. (2017) reported a saving of 52% in labour by machine milking. It can be concluded that machine can be used in smaller, medium or bigger herd. Machine milking is appropriate for larger herd having higher milk productivity than in the smaller herd with lower milk productivity. Greater saving in labor can be achieved by the use of two or more number of cluster in larger and higher producing herds.

Table 5 Labour requirement and efficiency between hand and machine milking in this study

Milking methods	Average daily production per cow (kg)	No of cow	Labour required				Total daily milk yield(kg)	Milk obtained per hour of labour (kg)
			Milking time only (min)	Equipment cleaning and sterilizing time (min)	Total daily time taken (hr)	Labour hour per week		
Machine milking	7.21	17	Per cow per day: 10.33 Time per day for single cluster: 175.61	20	3.26	22.82	122.57	37.59
			for two cluster: 92.97	20	1.88	13.16	121.89	64.83
Hand milking	7.58	17	Per cow per day :23.82 Time per day:404.6	10	6.91	48.37	128.86	18.64
Saving in labour by machine milking (%) a) Single cluster					52.82	53.40		
b) Double cluster					72.79	73.08		
Percent more milk obtained by machine per hour (%) a) Single cluster								101.66
b) Double cluster								247.80

3.6.2 Financial aspects of machine milking versus hand milking

The prime motive of using machine for milking is considerable saving in labor wages expenses because investing in machine is one of the costly activities. We determined the associated cost of milking herd consisting of an average of 17 cows. The calculated values are shown in Table 6. From the table, in a herd in which 17 cows are being milked it requires 48.3 hours of labor per week for hand milking and 22.82 and 13.16 hours for single cluster and double cluster milking machine, respectively. The weekly labor cost for milking the herd by hand was NRs 3337 and for milking by single and double cluster machine were NRs 1574.58 and NRs 908.04, respectively. The total weekly overhead costs of the machine for single and double cluster machine were NRs 445.70 and NRs 460.93, respectively. By adding all associated cost, total cost for single and double cluster machine milking resulted to NRs 2020.28 and NRs 1368.97, respectively. Finally, the weekly cost saving achieved by our result were 39.47% and 58.98% for single and double cluster machine respectively. An economical aspect of the milking machine use is basically proportional to the size of the herd and operator skills. It can be concluded that investing in machine makes farms to milk more cows and produce more milk with less labor and time. However, labour so saved must be involved in other fruitful tasks or paid in hourly system.

Table 6 Financial aspects of machine milking versus hand milking

Parameters	Single cluster type	Double cluster type
Initial cost of machine (NRs)	90000	120000
Average annual investment (NRs)	53550	71400
Annual interest @ 6% (NRs)	3213.00	4284.00
Annual machine run time (hr)	1186.64	684.32
Electricity cost (NRs)	9163.23	5284.32
Annual repair and maintenance cost @3% (NRs)	2700	3600
Assumed economic life of the machine (years)	10	10
Salvage value (s)@ 10% of machine price (NRs)	9000	12000
Annual depreciation value @10%(NRs)	8100	10800
Annual variable cost (NRs)	11863.23	8884.32
Annual fixed cost (NRs)	11313.00	15084.00
Total cost per week(NRs)	445.70	460.93
Hand milking labour per week (hr)	48.37	48.37

Machine milking labour per week (hr)	22.82	13.16
Cost of hand milking (NRs)	3337.53	3337.53
Cost of machine milking (NRs)	1574.58	908.04
total cost of machine milking (NRs)	2020.28	1368.97
Weekly saving in cost (NRs)	1317.25	1968.56
% cost saving	39.47	58.98

Note: Using One dollar is equivalent to NRs 113.85; the cost of 1 KW h in Nepal is equals to NRS 7.8 (NRB, 2020)

1 hP motor consumes 0.99 Kwh @ 75% efficiency; Electric power consumption @ Rs 7.8 per kwhr (NEA, 2017) ; Straight Line Depreciation method: $D = (P - S)/ N$ (FAO, 1992)

Where, D= depreciation, NRs yr^{-1}; P=purchase price, NRs; S= salvage value, NRs; N=useful life of the machine, year

Average annual investment $AAI = (P - S) (N + 1)/ (2N) + S$ (FAO, 1992)

Annual fixed cost= depreciation + interest on investment

Annual variable cost= electricity cost +annual repair and maintenance

Hourly minimum wage rate= NRs 69 (MOL, 2018)

4 Conclusions

1) There was no significant difference in the daily milk yield and milk composition from machine milking compared to hand milking.

2) Milking machine significantly shortened the cow milking time (54.8% -58.1% lesser) compared to hand milking.

3) Milking machine stimulates milk flow rate increment (percent) to more than one half of the hand milking.

4) The use of a milking machine saves more than one half the labor and cost required for milking a herd of 17 cows depending on the number of cluster used at the same time for milking.

Overall, from our findings, we suggest that milking machine could be one of the beneficial and efficient options for reducing the production cost and improving labour efficiency in milking task without deteriorating milk quality with respect to hand milking. Importantly, an economical aspect of the milking machine use is basically proportional to the size of the herd and operator skills. However, further investigations using long term machine use would be required in order to obtain data, which could be used for short term and long term impacts on udder and tissue health, and long term economy of regular machine use.

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Graphical Abstract