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Development and Performance Evaluation of Machine-Type Reciprocating Churner

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ABSTRACT

One of the old methods of butter production, which is still used in parts of Africa and the West of Asia, is the process of churning in the skin of a goat or deer that is half filled with milk or yogurt and air, which is beaten reciprocating. This type of butter production in the current research is mechanized and is called machine-type reciprocating butter churner (MRBC). This device is composed of chassis, churner, churn carrier, connector or crank, rotating wheel, driving system or power transmission and balance weights. In order to evaluate MRBC, the effect of churning amplitude (40, 60 and 80 cm), churning frequency (50, 61 and 72 cpm) and the churner volume (13.5 and 21.3 liters) on the butter yield was investigated. The results showed that the amplitude, frequency and churner volume had a significant effect on the butter yield at the level of 1%. Regardless of the churner volume, the minimum and maximum butter yield was obtained in the lowest and highest amplitude and frequency, respectively. The present study gives a general overview of the butter yield affected by machine mechanical parameters.

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INTRODUCTION

Butter making is one of the oldest forms of preserving the fat component of milk. Its manufacturing dates back to some of the earliest historical records and references have been made to the use of butter in sacrificial worship, for medicinal and cosmetic purposes and as a human food long from the Vedic periods (Khademi & Masomi, 2022). Butter is produced by the churning process on fresh or fermented milk or cream and contains milk fat and protein and water (Aryana, 2017). Common types of butter include butter made from cream and butter made from yogurt, which can be made from yogurt made from cow, sheep, and goat milk. The diversity of climate, flora, fauna and in general the ecosystem of each region has a significant impact on the physical, chemical and microbial characteristics of the resulting butter (Sağdıç et al., 2004). In traditional methods, a part of the churn is filled with cream at a temperature of 8-10°C and subjected to mild tension and aeration and sometimes sudden shocks resulting from the churning of the churn. The instability of the emulsion leads to the production of small grains of butter floating in the watery part of the cream. The buttermilk is removed and the process of texturing the fat mass and removing the remaining moisture continues. This causes the butter to become a hard mass. In the traditional type, butter has 65% fat and 30% water, while industrial butters have nearly 80% fat and less than 15% water (Idoui & Karam, 2008; Aryana, 2017). A variety of methods and devices have been developed to produce butter on a small scale. Butter was first made by placing the cream in a leather container made from goat's stomach skin and shaking until the milk was broken down into the butter (Eltayeb & Mahjoub, 2003). Different materials such as animal skin, wood, earth, and metal are used for traditional churns. For a skin bag churn, a goatskin or a sheepskin is used. A goat or a sheepskin is dried, kept in hot water, and hairs are removed. Following second time drying, fatty tissue is removed. The cleaned and dried skin is kept in boiling water containing pomegranate skins, and dried for the last time. This procedure takes about a week. Finally, the openings of the skin are tied up with threats and hung down vertically from a wooden stand with ropes. Churning is a tedious process as it requires manpower. The skin bag churn is shaken backward and forward by a person until butter is separated from serum. In another form of skin bag, the skin is prepared as a big cloth with a big opening on the top. It is hung vertically. A hand-operated long wooden plunger is used for mechanical agitation. In this case, the plunger is moved up and down until butter is produced (Aryana, 2017). Butter churns have varied over time as technology and materials have changed. The first butter churns had a wooden container and a plunger to agitate the cream until butter formed, referred to as a plunge churn or dash churn. Then, butter churns consisted of a container made from wood, ceramics or galvanized iron that contained paddles. Later centrifugal type butter churns were introduced for butter making. Instead of having spinning paddles, the paddles are fixed and the container spins. This allows better separation of butter from butter milk (Khademi & Masomi, 2022). At the end of the eighteenth century, the construction and use of creaming and butter making equipment (other than that made of wood) began to receive consideration, and the barrel churn made its appearance (Kalla et al., 2016). Siddique et al. (2011) optimized and evaluated the traditional butter making methods for getting good quality and yield of butter by standardizing cream fat levels and altering churning temperatures during butter making. Another research discussed on automating butter churning process by utilizing digital signal processing techniques based on the sound from the churning process. The process involve three phases on the base of sound characterizes in each levels. In first stage, the team record churning phase, second stage with butter-begin phase, where the butter start forming, and final butter collection, where the butter particles gathered. Artificial neural network was used to classifier. Results show that the sound of each phase can be used to characterize the phases of the churning process (Aljaafreh, 2011). An artificial neural network (ANN) model was developed for churning speed control by experienced operators for continuous butter manufacturing. A forward selection method was effective to select the proper input variables to the ANN model and four inputs including the cream flow rate, fat content, aging time and cream temperature were selected. The ANN model was then successfully applied to predict a churning speed within the prediction error of 7.0% compared to those of experienced operators (Shimada et al., 2013). Gorde et al, (2020) investigated on pedal operated churner to improve efficiency and provides affordable rate to normal milkman. This project seeks to develop butter by means that of combination using bicycle & mechanism. They used pulley belt mechanism which is drive by bicycle. They found that the mechanism helps to reduce human effort and churning time. It is affordable for rural people and considerably reduces time, efforts with highest possible economy.

A manufactured electric churn with a single semi-helical stirring paddle, arranged horizontally at the end of a vertical shaft, was used. The research showed that the higher the speed of the stirring paddle is, the smaller the churning yield obtained, regardless of the initial fat content of the cream.

For the samples where a higher speed was used, there were higher losses of fat in the buttermilk, which causes a low butter yield of the process (Stana et al., 2023). The butter production in rural areas of Iran is still not technically advanced and people still prefer local traditional method which yield low quantity butter. However, there is no adequate information on the effects of machine-type reciprocating butter churner on quantity of butter produced. Therefore, to predict the optimum churning conditions, a machine-type reciprocating butter churner was developed and the effect of three important parameters viz. amplitude, frequency, and churner volume were studied on butter yield (quantity of butter produced).

MATERIALS AND METHODS

The present invention relates to a method of producing butter, is a machine-type reciprocating butter churner (MRBC) apparatus. The intended apparatus for this purpose consists of chassis or stand (1), churn (2), churn carrier (3), connector or crank (4), rotating wheel (5), driving system or power transmission (6) and balance weights (7) which are the main components of the apparatus as shown in the Fig. 1. Selection of proper materials for making of various components of MRBC was very important.

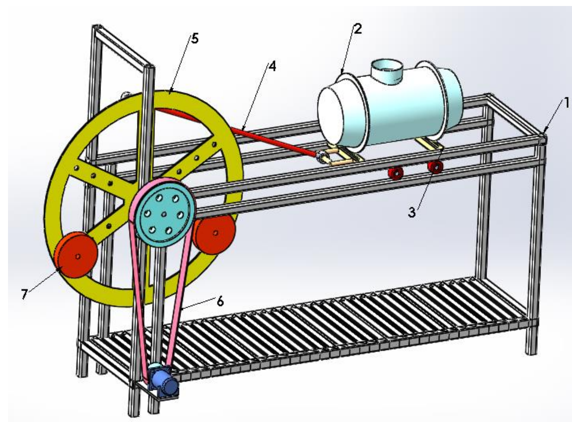

Figure 1. Schematic of MRBC

The shaft material was selected based on considerations such as high strength, capable to be heat treated and good machinability. The diameter of the drive and driven pulley was 100 mm and 300 mm, respectively. The 4 hp three phase A.C. motor was used with rated speed and frequency of 1400 rpm and 50 Hz respectively. The gear box system of 1:40 ratio was used to reduce the speed of motor to required churning frequency. The dry bulb temperature of ambient air and chilled water temperature was determined using glass thermometer. The experimental evaluation was conducted by using 3.5 litter raw milk from lactating cows. As raw milk and yogurt production methods vary, butter available in the MRBC maybe differ, therefore, various factors viz. cattle feed, age, type of diet and breed were kept constant. Yogurt was prepared by traditional method; milk was taken to the laboratory and heated and boiled at 90°C for 3 minutes (pasteurized) and the cooled to 45°C. The 4% fat yogurt was procured from the Kale's factory, Kerman Iran and then about one tablespoon of yogurt (starter) were added to each milk vessels and incubated at 37°C for 24 h after formation of yogurt it was cooled under refrigeration temperature. After the raw milk became yoghurt the added the drinkable and free from contaminants, the churning was undertaken in the effects of MRBC. In churning process, the fatty particles from yogurt mixture gets separated and forms layer at the top of the vessels due to density difference. This layer is then collected and known as butter (Fig. 1). The fat content of milk and buttermilk samples was determined using the Gerber method. Analysis of variance to evaluate the effects of the churning amplitude (40, 60 and 80 cm), churning frequency (50, 61 and 72 cycles per minute, cpm) and the churner volume (13.5 and 21.3 litters) of MRBC was performed on the butter yield.

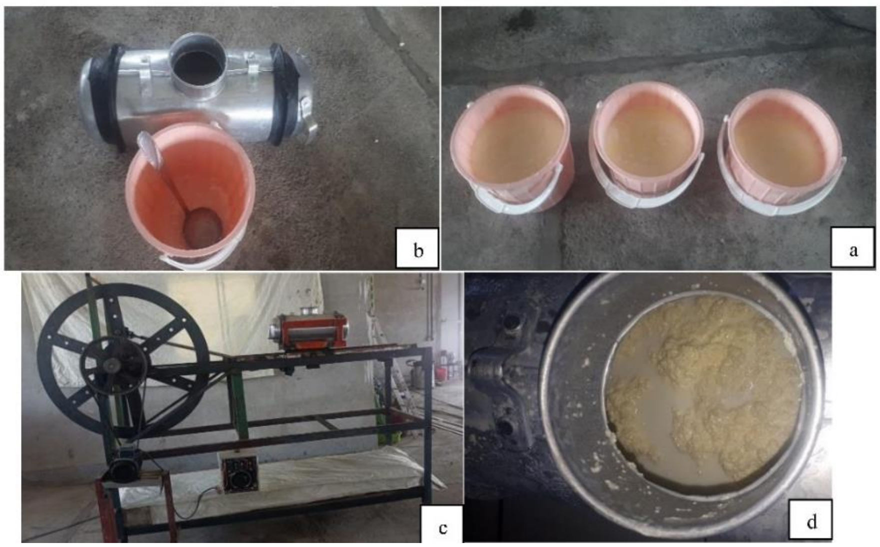

Figure 2. View of MRBC and butter manufacturing. **a** Yogurt vessel, **b** Yogurt unloaded in the churn, **c** machine-type reciprocating butter churner (MRBC), **d** Formation of butter grains

RESULTS AND DISCUSSION

The statistical results pertaining to the effect of churning amplitude, churning frequency and churner volume on the butter yield revealed that the butter yield of samples is significantly ($p \leq 0.01$) affected by the amplitude, frequency and volume. The interaction effect between the amplitude and volume and also frequency and volume had shown significant ($p \leq 0.05$) effect on butter yield (Table 1). Butter grains are formed by breaking down the membranes that surround the fat.

Cinnamon flavored Butter Milk was developed by addition of cinnamon powder in Butter milk and investigating the proximate quality, textural characteristics, keeping quality and sensory attributes of the developed product. The organoleptic studies appearance, color, flavor, taste, mouth feel and overall acceptability were studied and overall acceptability was good for Cinnamon Flavored Butter milk. The Shelf life of Cinnamon Flavored Butter Milk was better compared to normal buttermilk and recommended for market exploration (Palthur et al., 2014).

Table 1. The analysis of variance for the effect of test factors on butter yield

Source of Variation	DOF	Sum of Squares	Mean of squares	F Value
Churning Amplitude (A)	2	35305.4	17652.7	44.27**
Churning Frequency (F)	2	48383.2	24191.6	60.67**
Churner Volume (V)	1	84150.8	84150.8	211.03**
A×F	4	1358.0	339.5	0.85ns
A×V	2	3820.9	1910.4	4.79*
F×V	2	3076.6	1538.3	3.86*
Erorr	40	15950.7	398.8	

ns: not significant, *: significant at/above 5% level, **: significant at/above 1% level

A study was conducted to evaluate butter making efficiency, churning time and butter amount obtained from the traditional butter churner (clay pot) in relation to improved manual butter churner in Sidama zone. Significantly higher quantity of butter (0.41 kg/5liter) at P>0.5 was obtained from improved churner than traditional clay pot (0.26kg/5liter). Furthermore, the traditional mechanism of butter processing took significantly longer churning time (59 min.) than improved churner (26 min) (Tsedey et al., 2018). The efforts were made to optimize the batch butter making process to obtain a high yield and good quality of butter. The effect of churning temperature and churn speed on the churning time and other butter output were investigated. The churning temperature and churn speed and their interaction showed a significant effect on churning time and quality of butter (Kalla et al., 2015).

The effect of churning amplitude, frequency and churner volume the yield of butter is shown in Fig. 3 and 4. By increasing the amplitude, frequency and volume, the butter yield increased and reached a significantly (P< 0.01) higher value. When the amplitude is lower, a small proportion of the fat phase may remain in the globules after churning, and as a result, the amount of butter decreases. This revealed that the yield increased from 230.07 to 289.85 g when amplitude of churning increased from 40 to 80 cm. The increasing trend in yield butter with increase in churning frequency might be due to the reason that at higher frequency there is a different effect on the structural integrity of the fat globules of butter and relatively high proportion of the fat phase may remain in the globules after churning. A motorized milk churner was developed and its performance evaluated. The machine is powered by a 1hp speed electric motor. The highest and lowest butter yield recorded during the tests was 58.90 gm/lit and 50.76 gm/lit respectively at an operating speed and churning time of 180:25 and 180:20.42 respectively. The machine can be used for small and medium scale milk production to encourage butter production in Ethiopia (Lema & Hailu, 2024). The increase in yield butter with increase in churner volume might be due to the reason that the agglomeration of fat globules occurs more rapidly at higher volume, as a result the butter grains formed would be bigger. As a result of the severe impact of the fat molecules in the yogurt on the bigger churn, the molecules break and turn into butter. The butter yield was recorded to be highest 294.04 g at high volume of 21.3 L and the lowest value recorded was 215.09 g at lower volume of 13.5 L.

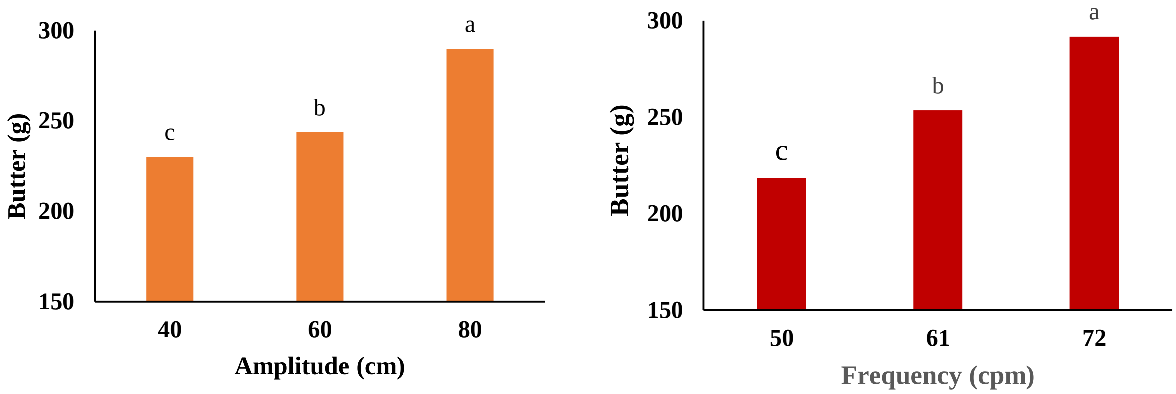

Figure 3. (Left) The effect of churning amplitude and (Right) the churning frequency on the butter yield

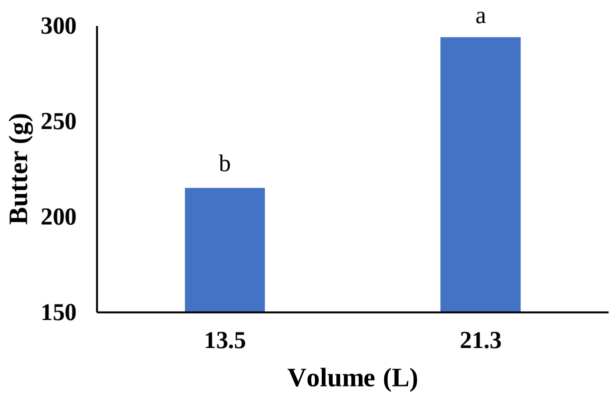

Figure 4. The effect of churner volume on the butter yield

The yield had increased with increase in amplitude. This might be due to higher fat penetration into butter aggregates during high churning amplitude. It was found that the butter values are significantly different in different amplitudes and frequencies. Buldo et al. (2013) reported that longer ripening time (5 h vs. 0 h) resulted in larger butter grains (91 vs. 52 µm), higher viscosity (5.3 vs. 1.3 Pa.s) and solid fat content (41 vs. 3 %). Despite the increase in solid fat content, no further changes in crystal polymorphism and in melting behavior were observed after 1 h of ripening and after churning. Kalla et al. (2016) attempted studies on churning operation to optimize churning parameters such as churning temperature and churning speed using a batch type mechanized frustum cone shaped butter churn. The optimum parameters of churning time (40 min), moisture content (16%) and overrun (19.42 %) were obtained when cream was churned at churning temperature of 10°C and churn speed of 60 rpm.

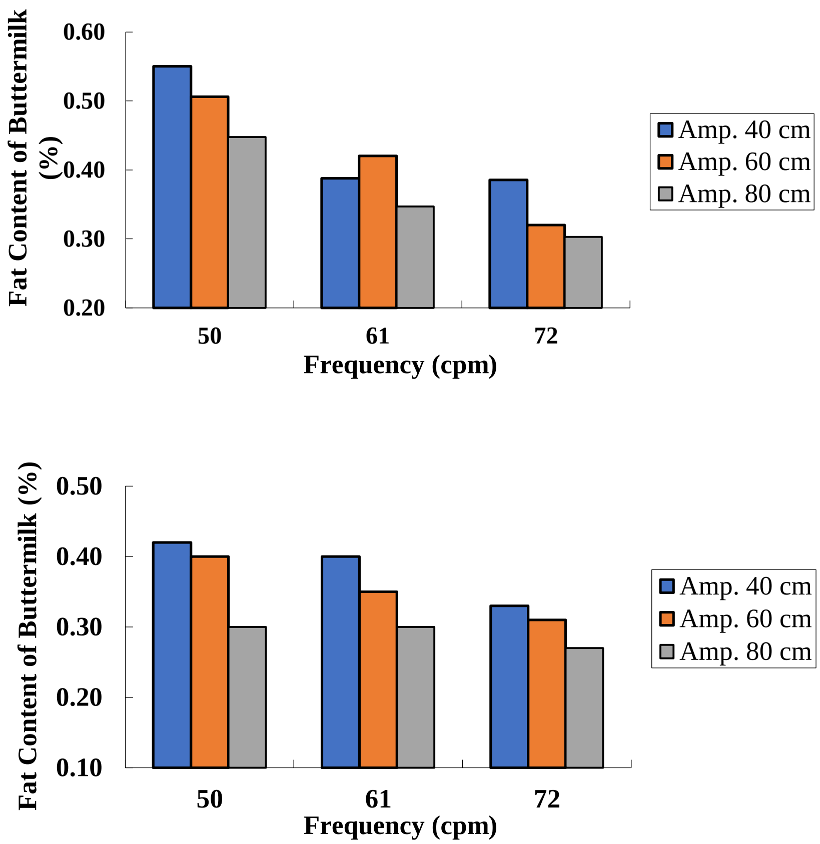

Figure 5. Effect of churning frequency and amplitude on fat content of buttermilk for churner volume 13.5 L (top) and 21.3 L (down)

While experiments, the yogurt is churned and worked and during these steps yogurt fat globules aggregate to form butter grains. Aggregation of butter grains leads to a phase inversion of the emulsion and entails the separation of the water phase (the buttermilk). Figure 5 represents the effect of churning frequency and amplitude on fat content of buttermilk for two churner volumes produced by MRBC. The figure shows the decreasing trend in fact content of buttermilk with increase in the churning frequency and amplitude. This might be due to the chemical composition of buttermilk, with increase in churning frequency and amplitude the fat content has decreased because yield butter increased. The amount of fat in the obtained buttermilk decreases with the increase in frequency, i.e., the speed of going back and forth, regardless of the amplitude. As the butter yield increases, as a result, the amount of fat in buttermilk decreases. The high fat content of buttermilk (0.55 %) was achieved at lower frequency (50 cpm), amplitude (40 cm) and churner volume (13.5 L). But lowest fat content (27 %) was obtained at higher frequency amplitude and churner volume of 72 cpm, 80 cm and 21.3 L, respectively. The lowest and highest fact content of buttermilk was obtained in larger and smaller churner volumes, respectively.

Sun et al. (2007) and Sun et al. (2013) did investigations on alternative method by utilizing Stirling cooler for butter churning. They reported that water content of the butter was lower while the fat content was higher in butter samples obtained by this machine. A high temperature during the churning process reduces the butter yield, as some of the butter fat liquefies and is lost with the buttermilk. A number of interrelated variables are involved in efficient operation of butter churn machine, such as fat level, cream acidity, churning temperature and churn speed.

CONCLUSIONS

In this research, a machine-type reciprocating churner was designed and evaluated. The effect of amplitude, frequency and churner volume was significant at the level of 1% on the butter yield. It was found minimum of 215.09 g butter yield at the 21.3 L volume churner and the maximum of 215.09 g was obtained at the 13.5 L volume churner. It was found high fat of buttermilk (0.55%) at the churning frequency 50 cpm, amplitude 40 cm and churner volume 13.5 L. Also, it was found that the butter yield is significantly different in different amplitudes and frequencies. However, these conclusions are based on a model system study in which conditions (e.g., churning amplitude, frequency, and churner volume) differ from the typical butter-manufacturing plant. The present study gives a general overview of the butter yield affected by machine mechanical parameters. Therefore, the dairy industry will benefit from these insights on the optimization of butter manufacturing.

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