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Physical and thermal properties of corn cob powder blended mud cup (*khulad*)

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ABSTRACT

Physical properties and thermal properties of corn cob powder blended mud cups were measured for assessing the feasibility of partial replacement of mud by corn cob powder as an agro biomass utilization process. Corn cob was collected from the fields of Ludhiana district (Punjab, India) and further work was carried out at ICAR-CIPHET, Ludhiana during 2019. The corn cob powder (5, 10 and 15%, g/g) blended mud cups were prepared by baking the molded cups in a direct fire.The physical properties like surface area (84.61–92.59, cm^2); ratio of surface area to volume (1.01–1.27), density (0.83–1.09 g/ml), compressive force (96.57–170.8 N); and thermal properties like thermal conductivity (0.132–0.192, w/mK), specific heat (1.075–0.142, J/kg) and diffusivity (0.132–0.137, mm^2/s) and Newton's cooling constant (0.49–0.54, 1/min) of the prepared cups were analyzed. The results showed that the corn cob powder can be added up to 15% (w/w) further addition reduced the physical and thermal properties of the cup.

Keywords: Biomass utilization, Corn cob powder, Mud cups, Physical properties, Thermal properties

Mud cups (*khulad)* are used for serving foods and it is considered as unique tradition of India. These were made using red mud with good workability which is available at certain places only. Moreover mud available from different geo-spatial sources affects its properties (Oyanedel and Smith 2007, Nandi *et al.* 2008, Plappally 2010). Due to urbanization and continuous depletion of nature, the red mud availability is also in scarcity which affects the making of such mud cups, because of which other alternatives such as plastic, metals and porcelains are used for making cups. But these materials are discouraged by consumers due to related health issues. Moreover, such material took many years to degrade and causes more pollution and thus affects the fauna of nature. In order to increase the manufacturing of traditional potteries and to reduce the depletion of finite natural resources, alternative biomass materials and agricultural waste materials are encouraged to use (Nandi *et al.* 2008). Wastes generated from various agricultural activities and agro industries such as rice husk, saw dust, corn cobs etc can be used as source materials for alternative purposes (Freire and Beraldo 2003). Biomass wastes were successfully used for manufacturing of building materials like bricks with improved properties and durability (Malaiskiene *et al.* 2011).The mixture of mud/clay and plant residues such as rice husk, wheat straw, sawdust and other agricultural residues could be used as basic ingredient for making ceramic devices (Hwang 2003, Oyanedeland Smith 2007, Klarman 2009). Slight variations in composition of these mixture alters the micro-structural, physical, mechanical and thermal properties of ceramic devices and also redefines their strength (Gladkov 2003, Plappally 2010).The structural integrity of the device manufactured from clay-composites was maintained by optimal addition of residual materials due to more cohesive nature of mixture (Papargyri *et al.* 2003, Lantagne *et al.* 2010, Chandramohan and Marimuthu 2011).With this background, the main objective of the present study was to investigate the feasibility of partial replacement of mud using corn cob powder for making mud cups based upon its physical and thermal properties.

MATERIALS AND METHODS

Preparation and properties of corn cob powder: Whole corn cob was collected from the fields of Ludhiana district (Punjab, India) and further work was carried out at ICAR-CIPHET, Ludhiana (2019). The corn cobs were cleaned, milled using hammer mill and sieved by manual sieving to obtain less than 1 mm particle size corn cob powder. The powder was dried at 105ºC for 3-4 h to reduce its moisture content. Prepared corn cob powder was stored in air tight container. The bulk density of powder was calculated by

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Gupta *et al.* (2017) and thermal properties were determined using the thermal property analyzer (Model KD2, Decagon Devices Inc., WA, USA) (Jagannadha *et al.* 2009).

Preparation of cups: Corn cob powder was mixed with the mud in the ratio of 5, 10 and 15%. The water was added to the mixture and kneaded well for workable consistency. The cups were molded by outsourced skilled person. Then the molded cups were baked in a direct fire at 900-1100ºC. Mud cup prepared without addition of corn cob powder was used as control.

Measurement of physical properties: Dimensions of the prepared cups, i.e. height, thickness, inner diameter, outer diameter, bottom thickness were calculated by using measuring scale and caliper. The volume and surface area of the cup was calculated using equations (1 and 2) and Surface area to volume (SA-V) was estimated by taking the ratio from surface area to volume. Density of the cup was measured by soil displacement method (Gupta *et al.* 2017). Compression force was measured using Texture Analyser (Model 5566) using load cellas described by Brown and Soboyejo (2011). The prepared cups were compressed between parallel plates applying a sustained static load of 500 kg to the large (bed) face at the speed of 0.033 mm/sec. Compression force was expressed in kg. The tests were conducted at room temperature.

$$\text{Volume of the cup, cm}^3 = \frac{1}{3}\pi h\left(r^2 + \text{rR} + R^2\right) \tag{1}$$

Total surface area of the cup, cm^3 =

$$\left(\pi\left(r+R\right)\sqrt{\left(R-r\right)^2+h^2}\right)+\pi r^2+\pi R^2 \tag{2}$$

where, h is the perpendicular height of the cup, cm; r is the small radius of the cup, cm; and R is the big radius of the cup, cm.

Measurement of thermal properties: The thermal properties of corn cob powder blended cups were determined using the thermal property analyzer (Jagannadha *et al.* 2009). The thermal property analyzer had consisted of one stainless steel needles which acted as line heat source element and a temperature sensor. A micro-controller had regulated the power supply to the heating element to vary the temperature differences and the sensor measured the temperature. The thermal conductivity, specific heat capacity, diffusivity and resistivity of the test sample were determined by in-built software by the theory of transient heat transfer analysis. The least count of the analyzer was three decimal with the corresponding accuracy of 100% each. Before measurement, the analyzer was calibrated against distilled water as per the procedure described by the manufacturer and then used for measurement of cup thermal properties. A hole on the rind of the cup was made to keep the needle for measurement. Each of these measurements was replicated thrice and average values were taken.

Estimation of cooling constant: Cooling constant of corn cob powder blended mud cup was estimated by using Newton's Law of Cooling equation. The change in temperature was plotted against the time of cooling and regression analysis was performed to obtain the cooling constant.

$$\text{T} = T_0 e^{-r\tau} \tag{3}$$

where, τ is Newton‘s cooling constant/min, T is the difference between water at time t (T_t) and ambient temperature (T_a); (T_t - T_a) and T_0 is the difference between initial water (T_i) and ambient temperature (T_a); (T_i - T_a).

Statistical analysis: Experiments were performed in triplicates and the data are reported as mean ± standard deviation. Regression analysis was done using Microsoft Excel.

RESULTS AND DISCUSSION

Corn cob powder blended mud cups: The engineering and thermal properties of corn cob powder analyzed are given in Table 1. Further the corn cob blended mud cup were prepared and analyzed for its physical and thermal properties.

Physical properties

Surface area: The surface area of the corn cob powder blended mud cups was calculated as 92.59, 89.13, 86.15, and 84.61cm^2 for 0, 5, 10 and 15% respectively. From the results, the surface area got reduced as the corn cob powder percentage increased. It may be due to shrinkage or contraction of fibers present in the corn cob powder during drying and baking. The fibers in the corn cob powder got swelled due to wetness of the mixture. So once when it dried, the all fibers got shrink and thus it might reduce surface area. The contraction of fiber during heat treatment is reported by Chandrasekar, Kailappan, Kasthuri, and Rajamani (2013).

Surface area to volume: Surface area to volume (SA-V) is the ratio of the surface area of cup to volume of the cup. It states the quantity of surface area per unit volume of the cup and it is an important parameter for the chemical reactivity. In present study, it indicates the interaction of medium filled in the cup with the surface of the cup. More ratio of surface area to volume means more interaction and vice versa. The ratio of surface area to volume was found to be 1.27, 1.2, 1.09 and 1.01 for 0, 5, 10 and 15% respectively. There was 20.47% of reduction observed in the surface area to volume as percentage of corn cob powder increased from 0 to 15%. It is due to contraction of fibers present in the corn cob powder during heat treatment is reported by Chandrasekar, Kailappan, Kasthuri, and Rajamani (2013). The results showed that the reactivity of corn cob powder blended mud cup was less compared to other cups, so corn

Table 1 Engineering and thermal properties of corn cob powder

Properties	Values
Bulk density, g/ml	0.227
Thermal conductivity, w/mK	0.146
Specific heat capacity, mJ/m^3/K	0.763
Diffusivity, mm^2/s	0.146
Resistivity, mk/w	6.849

blended mud cups can also be used for storage of some chemical solution.

Density: Density of mud cup was found to be 1.09, 1.06, 0.92 and 0.83 kg/m^3 with percentage increase in corn cob powder from 0–15% (w/w) and observed that about 23.85% of density decreased with increase in percentage of corn powder. The decrease in density was due to volumetric contraction of fibers in the corn cob after firing of mud cup and due to weaker bond established between the mud and the corn cob powder. Kadir and Maasom (2013) reported that density of 1 and 3% of sugarcane bagasse bricks decreased due to pores and weaker bonds between particles after firing. Similar trends were reported for sugarcane bagasse ash incorporated bricks by Ali *et al.* (2016). It was reported that the average density of ceramic ware made from porous clay increased with increase in addition of saw dust (Brown and Soboyejo 2011). The contradiction of these results might be due to smaller size particles of saw dust (35-1000 mesh) than corn cob powder (1753–6200 mesh). The saw dust might get stuffed into pores of the porous clay and made the clay compacted. Thus, it might cause increase in density.

Specific heat: Specific heat of mud cups found to be 1467, 1.391, 1.538 and 1.479 kJ/kg K m^3 with percentage increase in corn cob powder from 0–15% respectively and observed that no uniform trend was observed in specific heat with respect to increase in percentage of corn cob powder. Goto and Matsubayashi (2009) reported that specific heat of clay and sandy sediments increased with increasing porosity. On other hand, Oladunjoye and Sanuade (2012) observed decreases in specific heat with increase in porosity. Specific heat varied with the change in percentage of corn cob powder blend.

Compression force: Compression force of the cup was measured to check the ability of corn cob powder blended cup to withstand the maximum force act on it. The compression force of the mud cup ranged from 170.08–96.57 kg and found that it was decreased with increased percentage of corn cob powder from 0–15% (S Fig 1). About 43.22% of compression force reduced due to addition of corn cob. The decrease in compression force indicates the decrease in compression strength of the corn cob blended cup. The addition of sugarcane bagasse ash reduced the strength of the compressed earth brick compared to the control brick as the brick becomes more porous with a higher percentage of sugarcane bagasse ash (Ali *et al.* 2016). The highest compressive strength for the brick was 22.80 kN/mm^2 followed by 14.16 and 5.84 k N/mm^2 for control, 1 and 3% addition of sugarcane bagasse, respectively (Kadir and Maasom 2013). The study found that the percentage of corn cob powder established a polynomial relationship with compression strength.

Thermal conductivity: From the result it was observed that the thermal conductivity of mud cup lied between 0.162 and 0.219 W/mk (S Fig 2). It is seen that the thermal conductivity changed with change in percentage of corn con powder blend from 0–15% and the variation of thermal conductivity was 26.03%. In a study by Kadir and Maasom (2013), reported that the thermal conductivity of 1 and 3% sugarcane bagasse added brick was 0.011 and 0.010 W/mK, respectively. The value of thermal conductivity of mud cup decreased with increased percentage of the corn cob powder. Decrease in thermal conductivity may be due to porous nature of corn cob powder and formation of pores on the cup during the firing process of mud cup. Rhee (1975) stated that the thermal conductivity of porous ceramic materials decreased with increase in porosity. The percentage of corn cob powder blend established a linear relationship.

Thermal diffusivity: Thermal diffusivity was found varied between 0.132 and 0.137 m^2/s, for change in percentage of corn cob powder between 0 and 15% (S Fig 3). Thermal diffusivity is in relation with thermal conductivity, density and specific heat capacity of the material. Goto and Matsubayashi (2009) reported that thermal diffusivity of clay and sandy sediments decreased with increased porosity. Result of the present study shows that no significant change in thermal diffusivity of cup. The relationship between thermal diffusivity and percentage of corn cob powder blend was found as linear.

Newton's cooling constant: Newton's cooling constant of mud cup was determined experimentally and it was observed that the Newton's cooling constant ranged from 0.49–0.54, 1/min (S Fig 4). As percentage of corn cob powder was increased, the Newton's cooling constant of

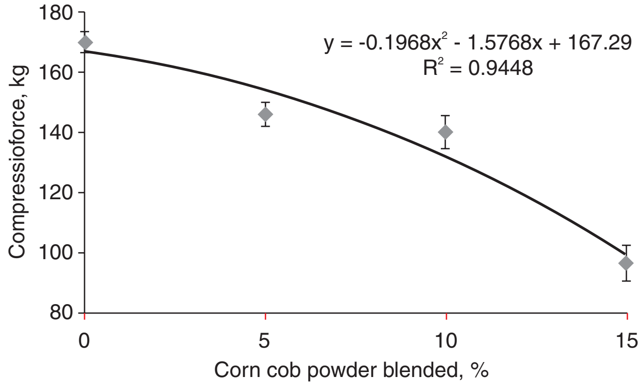

Fig 1 Effect of percentage of corn cob powder on compression force of mud cup.

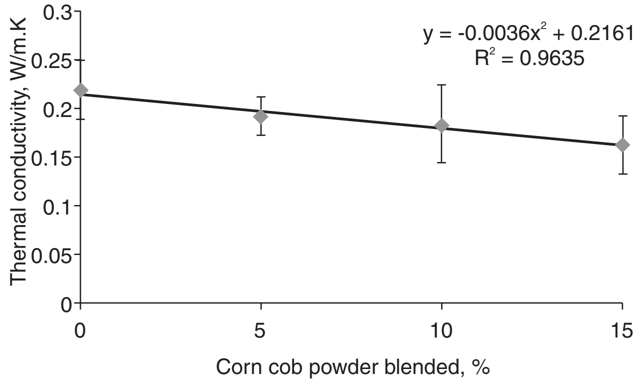

Fig 2 Effect of percentage of corn cob powder on thermal conductivity of mud cup.

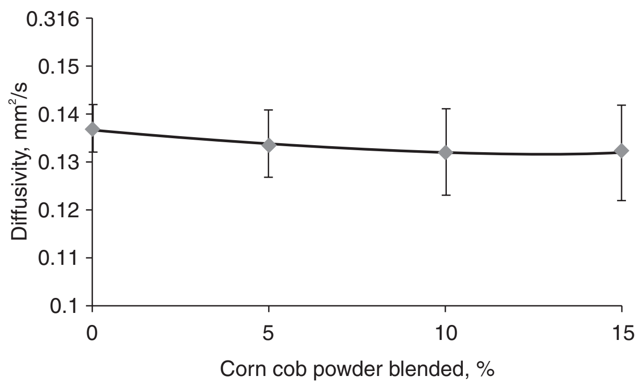

Fig 3 Effect of percentage of corn cob powder on diffusivity of mud cup.

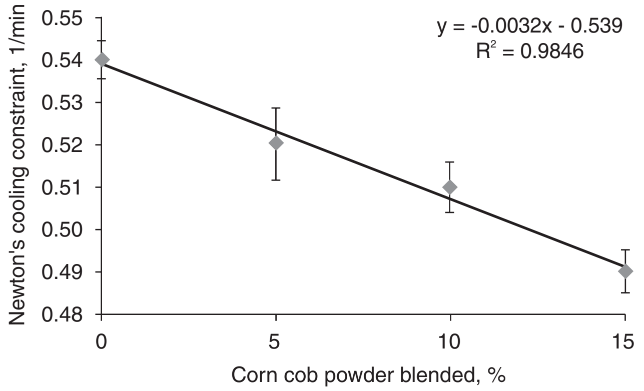

Fig 4 Effect of percentage of corn cob powder on Newton's cooling constant of mud cup.

mud cup was decreased. It is due to increase in porosity of the corn cob powder blended mud cups. Newton's cooling constant indicates that rate of cooling of the material present in the cup and explained that the rate of change in temperature of water in the pot is directly proportional to the temperature difference between water and ambient condition. Aravind *et al.* (2010) reported that when a hot liquid is kept in a cold cup then the mode of heat transfer occurs between hot liquid and cold cup due to conduction. High cooling constant indicates faster cooling of water. So, the result indicates that the corn cob blended mud cup retains the temperature of material present in it.

The results conclude that the corn cob residue can be utilized for making mud cup as a waste utilization and value addition process. The surface area, SA-V, density, compression force, thermal properties such as thermal conductivity, specific heat, diffusivity and Newton's cooling constant of corn cob powder blended mud cup decreased with increase in addition of corn cob percentage. The amount of corn cob powder addition established a linear relationship with all physical properties and both linear and nonlinear relationship with the thermal properties. The high regression coefficients (>0.90) of the relationships indicated that the models can be used to predict the physical and thermal properties of corn cob powder blended mud cup based on the percentage corn cob powder. This study also concluded that the agricultural biomass residues can partially be used for making cups along with mud. This type of biomass utilization provides an alternate solution for disposal of corn cob residues and other agricultural residues.

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