

Effect of natural clarificants on quality of jaggery

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Abstract

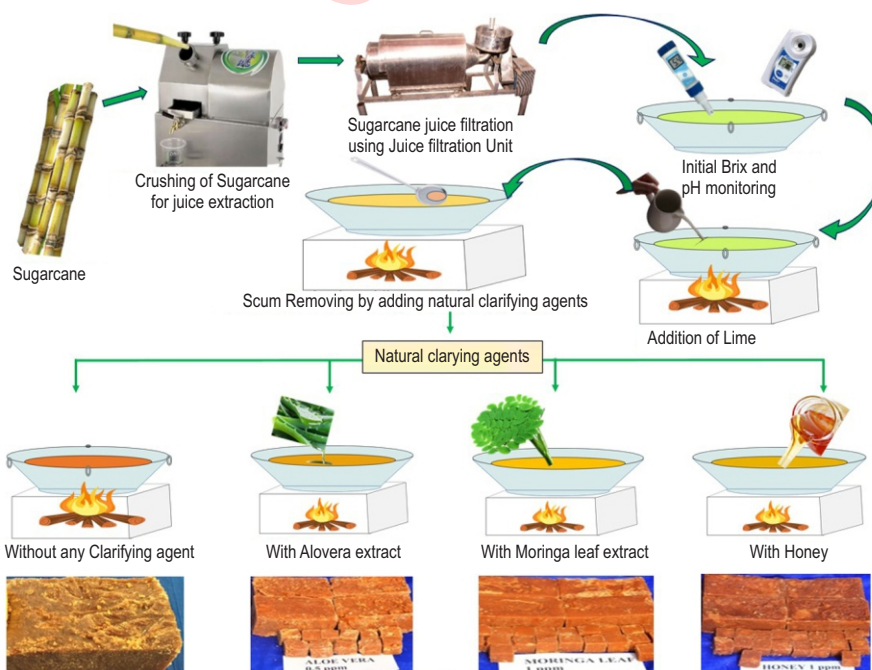
Aim: To identify and evaluate natural clarificants for jaggery preparation that improve colour and quality while ensuring product safety and avoiding the adverse health and shelf-life effects associated with chemical clarificants.

Methodology: Jaggery was prepared using different concentrations of natural extracts like moringa leaf extract, aloe vera juice and honey and determined for physico-chemical and sensory properties. Numerical optimization using Design-Expert was carried out to identify optimum concentration for good quality jaggery. Shelf-life studies were conducted using three different packaging materials.

Results: Jaggery prepared using moringa leaf extract was brighter in colour as indicated by higher L* values compared to other samples. Vitamin A and C content in jaggery increased significantly with increase in the concentration of moringa leaf extract and aloe vera juice. Numerical optimization revealed that 0.168% moringa leaf extract was optimum for producing good quality jaggery. Storage conditions for shelf-life up to 7 weeks in 3-layered metalized polyester pouches.

Interpretation: Moringa leaf extract at 0.168% is recommended as an ideal natural clarificant for producing good quality jaggery with improved functional and sensory attributes. It enhances the marketability, shelf stability and functional health benefits of jaggery, making it a promising step towards cleaner and safer commercial jaggery production.

Key words: Clarificants, Fuzzy logic concept, Jaggery, Sensory



Process steps for preparing high-quality, chemical-free jaggery using natural clarifying agents

Introduction

In India, the production and processing of jaggery plays an important role towards socio-economic development in rural regions (Madhu *et al.*, 2018). Jaggery contains high nutritive value and exhibits potential protective effects in individuals occupationally exposed to smoke-laden industrial environments (Sharon *et al.*, 2013). Nutritionally, jaggery is rich in proteins, essential minerals such as magnesium, potassium, calcium, phosphorus, iron, vitamins, essential amino acids, antioxidants, and phenolic compounds, making it a nutraceutical and a natural, nutrient-dense alternative to refined white sugar with potential health benefits and value in combating malnutrition and undernutrition (Nath *et al.*, 2015; Rao and Singh, 2022).

Traditionally, jaggery preparation involves several unit operations including the extraction of sugarcane juice, clarification, concentration through boiling, followed by cooling, moulding, and storage (Rao *et al.*, 2007). Usually jaggery farmers, use chemicals like 'Hydros' (sodium hydrogen sulphite; NaHSO₃), lime (calcium oxide), sodium bicarbonate, sodium carbonate, super phosphate and alum as clarificants for clarification of sugarcane juice during boiling. Several chemical clarificants, including polyacrylamide derivatives and ion exchange resins, are reported to cause severe health hazards due to the presence of traces of chemicals in the final product (Joshi and Abed, 2017). All these chemical clarificants except lime, brighten the colour of jaggery initially; however, the effect is not sustained during storage. Hence, there is a necessity to identify clarificants from natural source which can improve the colour and quality of jaggery. Plant-based clarificants are safe, natural and affordable options for making good-quality jaggery. Since these materials are not always available during production, a ready-to-use clarificant powder has been developed. A mixture of okra stem, soybean seeds, and fenugreek seeds was optimized to improve jaggery quality and appearance (Kumar *et al.*, 2022). Similarly natural plant mucilages from *Aloe vera*, fenugreek, flax seeds, purslane, and Malabar spinach have demonstrated improved scum removal, reduced processing time, and enhanced jaggery yield. These findings support the use of plant-based clarificants as sustainable alternatives to conventional chemical clarifiers in quality jaggery manufacturing (Nayaka *et al.*, 2018; Chikkappaiah *et al.*, 2017).

Vegetable clarificants such as okra mucilage, deola (*Hibiscus ficulneus*), colocasia, castor seed extract, groundnut, ambadi (*Hibiscus cannabinus*), phalsa (*Grewia asiatica*) and tapioca starch have been reported to effectively remove non-sugars, improve juice clarity, enhance sucrose retention, and reduce hygroscopicity, resulting in harder, crystalline, and hygienic jaggery with improved storability. Among these, deola-based clarification has shown superior colour, higher sucrose content, lower reducing sugars, and reduced moisture absorption at optimized dosages (Banerji, 2014). Furthermore, adoption of organic sugarcane cultivation and hygienic processing practices, with or without vegetable clarificants, contributes to the

production of high-quality organic jaggery (Singh, 2024; Sreedevi *et al.*, 2025). Existing studies on jaggery processing largely focus on conventional clarifying agents and general quality parameters, with limited scientific attention given to natural clarificants such as moringa leaf extract, *Aloe vera* juice, and honey. Comprehensive comparative evaluation of multiple natural clarificants within a single experimental framework is scarce, particularly regarding their effects on the physico-chemical characteristics, vitamin retention, and sensory quality. Quantitative assessment of vitamin stability in relation to clarificant type and concentration, along with advanced sensory evaluation approaches such as the Fuzzy Logic Concept and their correlation with instrumental quality parameters, remains inadequately explored.

Furthermore, the influence of natural clarificants on storage stability and their interaction with different packaging materials in terms of moisture migration, microbial safety, colour retention, and sensory acceptability during storage has not been sufficiently investigated. These gaps highlight the need for systematic optimization and holistic evaluation of natural clarificants in jaggery production. Therefore, the present study aims to investigate the use of natural clarificants, namely moringa leaf extract, *Aloe vera* juice and honey, in jaggery preparation, and to evaluate their effects on the physico-chemical characteristics, vitamin content and sensory properties of jaggery. The study further seeks to optimize the concentration of selected natural clarificants for the production of superior quality jaggery and to identify suitable packaging materials for extending the shelf-life of jaggery prepared with natural clarificants.

Materials and Methods

Raw materials: Fresh sugarcane variety 93A145 were harvested at the Regional Agricultural Research Station, Anakapalle, Andhra Pradesh, India. The sugarcane juice was extracted from the canes by using horizontal three roller crusher (Model: Saravana Horizontal type, Make: Kesavan Industries, Coimbatore, India). The harvested canes were manually fed to the crusher and the expelled juice was collected in a stainless steel settling tank to facilitate the separation of coarse suspended particles. Thereafter, the clear juice was drawn off from the settling tank filtered through a muslin cloth and transferred into a boiling pan for further processing.

Natural clarificants: Three natural clarificants, *i.e.*, aloe vera juice, moringa leaf extract and honey were selected and tested at four different concentrations (0.05, 0.1, 0.15 and 0.2 % v/v). *Aloe vera* juice was prepared by placing off the outer rind of fresh aloe vera leaves to obtain the inner clear gel, which was further blended using a blender. Clear aloe vera gel was placed in a blender (Make: Philips, Model: HL 1628). Moringa leaf extract was prepared by blending 100 g of fresh moringa leaves with 100 ml of distilled water using a blender (Make: Philips, Model: HL 1628). The mixture was carefully strained through a muslin cloth to extract the moringa leaf solution. Honey (make: Dabur) was procured from the local market in Anakapalle and was directly

added as an organic clarificant at different concentration. Each of these natural clarificants were added to the sugarcane juice at the respective concentrations during the clarification step of the jaggery preparation.

Jaggery preparation: Sugarcane juice was boiled in a stainless steel pan (304 grade) and clarified initially by adding lime that acted as a complexing agent. Calcium hydroxide (milk of lime), was added as a basic clarificant to remove impurities in the form of scum. Addition of lime simultaneously increased the pH of juice from 5.2-5.4 to 6.0-6.4, facilitating the coagulation of impurities, by neutralizing the juice and forming insoluble lime salts, which trapped and remove impurities such as pectins, proteins and coloured compounds. The resulting scum was periodically removed from the surface of boiling juice. However, excess lime increased turbidity and darkened the colour due to enhanced melanoidin formation under alkaline conditions, thereby maintaining an optimum pH (around 6.0–6.4) during liming which is essential for effective clarification and reducing turbidity (Laksa meethanasana *et al.*, 2012). Subsequently, one of the selected natural clarificants, *i.e.*, aloe vera juice, moringa leaf extract, or honey was added during the boiling phase, which helps in removal of suspended impurities through enhanced scum formation. Boiling was continued until the temperature reached approximately 120°C, and the total soluble solids (TSS) content increased to 81-82°Brix, resulting in a thick syrup. Clarification also have an impact on crystal morphology, colour, crystal content and polysaccharide content of jaggery (Sewwandi *et al.*, 2021).

Physico-chemical characteristics of solid jaggery: Non-reducing sugar content was determined using the method prescribed by the International Commission for Uniform Methods of Sugar Analysis (ICUMSA) as described by Johnson (1980), while reducing sugars were estimated using the Lane and Eynon method (AOAC, 2005). Hardness or degree of softening of jaggery samples was measured by determining the maximum penetration force. A texture analyzer (Make: TA-XT2i Stable Micro System, Survey, England) was employed for determining the hardness with respect to force (kg) required for penetration of probe (P/2) into the sample using the parameters pre-test speed (1 mm s⁻¹), test speed (1 mm s⁻¹), post speed (10 mm s⁻¹), trigger mode (Auto – 50 g) and dimensions of sample (25 × 25 × 25 mm) (Madhu *et al.*, 2017). Jaggery colour was analyzed in terms of L*, a*, and b* values using Spectrophotometer (Make: Colour Lab Model: SS5100) (Coyago-cruz *et al.*, 2019).

L* ranged from 0 to 100, 100 for white and 0 for black; positive values of a* indicated redness whereas negative values indicated greenness; positive values for b* represented yellowness whereas negative values blueness. The sensor was calibrated with a black and white standard tile to measure the colour. The moisture content was determined by vacuum drying method (AOAC, 2005). Jaggery samples (5 g each) were taken in a flat dish and placed in a hot air oven maintained at ≤70° C for 6 hr under pressure ≤50 mm Hg to remove water vapor. The dish was removed from the oven, covered, cooled in a desiccator and

weighed. They were redried for 1 hr and the process was repeated till change in between successive dryings at the interval was ≤2 mg. Low-density polyethylene (LDPE), aluminium foil, 2.5-layer metalized polyester and 3-layer metalized polyester pouches were used to study the shelf-life of jaggery using natural clarificants. Water vapour transmission rate (WVTR) and water vapour permeability were measured for all the four packaging materials according to method described elsewhere (ASTM, 2023; Madhu *et al.*, 2017) using thickness and area of the pouches. Sugarcane solid jaggery samples (25 g) prepared with natural clarificants (aloe vera juice, moringa leaf extract and honey) at different concentrations of (0.05, 0.1, 0.15 and 0.2 %) were sealed in four packaging materials. All these pouches were kept in an incubator at 25 °C for a period of 7 weeks. Physico-chemical analysis (moisture, hardness, colour, reducing sugars, sucrose) of samples was carried out as per the methods described in AOAC (2005) at an interval of one week till the end of storage period.

Vitamins A and C contents was estimated for jaggery prepared using natural clarificants at 0.1% concentration. Vitamin A content in jaggery was estimated following the method of Carr and Price (1926) described by Gwarzo and Muhammad (2010). Vitamin C content was estimated by 2,6 dichlorophenol-indophenol (DCPIP) (Merck KGaA, Darmstadt, Germany) titrimetric method (AOAC, 2005). Sensory evaluation was performed with 20 panelists and the fuzzy logic model was used for the analysis of sensory data (Chen *et al.*, 1983). Fuzzy membership function, normalized fuzzy membership function, judgment membership function matrix, judgment subset, quality-ranking subset and ranking of the sample were determined as per procedures described (Chen *et al.*, 1983; Jaya and Das, 2003).

The sensory evaluation focused on key quality attributes, including colour, taste, flavor, and texture/appearance. Jaggery prepared with various clarificants at different concentrations were marked as follows: S₁- Jaggery prepared with 0.05 % honey, S₂- with 0.1 % honey, S₃- with 0.15 % honey, S₄-with 0.2 % honey, S₅- with 0.05 % aloe vera juice, S₆- with 0.1 % aloe vera juice, S₇- with 0.15 % aloe vera juice, S₈- with 0.2 % aloe vera juice, S₉- with 0.05 % moringa leaf extract, S₁₀- with 0.1 % moringa leaf extract, S₁₁- with 0.15 % moringa leaf extract, S₁₂- with 0.2 % moringa leaf extract and S₁₃- control absence of clarificant.

Optimization of concentration of natural clarificant: The optimization of concentration of natural clarificant was carried out using Design-Expert (Stat-Ease Inc., 2007). Numerical optimization techniques available in the software were employed to maximize, minimize, or target individual responses as well as combinations of multiple responses. The optimum concentration of the clarificant was determined by defining specific goals for each response variable and assigning appropriate levels of importance, following the methodology described by Montgomery (2017) (Table 6).

Statistical Analysis: Observations were obtained from at least three independent experiments, each performed in triplicate, and

the results were expressed as mean \pm S.D. Statistical differences among the values were analyzed using Graph Pad Prism 5 software (GraphPad Software Inc., San Diego, CA, USA), with a p-value < 0.05 considered statistically significant.

Results and Discussion

Non-reducing sugars and reducing sugars contents of jaggery prepared using natural clarificants are given in Table 1. The results indicated that the addition of natural clarificants in the jaggery preparation increased the sucrose content significantly compared to control ($p < 0.05$). The maximum non-reducing sugar content of 87.88% was observed in jaggery prepared using 0.05% moringa leaf extract as a clarificant, followed closely by 87.85% in jaggery treated with 0.1% moringa leaf extract. These results are similar with clarification technique for producing quality jaggery with vegetables as clarificant agent by Mungare *et al.* (2000). However, the minimum non reducing sugar of 81.19% was observed in control jaggery without any clarificant agent. Reducing sugars play an important role in maintaining the colour of the jaggery and indicating the quality of the product.

The minimum reducing sugar content (10.39%) was observed in jaggery prepared with 0.05% moringa leaf extract as a clarificant, while the maximum (12.4%) was recorded in jaggery treated with 0.2% aloe vera juice. Lower levels of reducing sugars in the jaggery samples indicate reduced sucrose inversion and are indicative of better quality jaggery (Chand *et al.*, 2012). The use of *Moringa oleifera* leaf extract to aid impurity sedimentation in sugarcane juice treatment produced clearer juice and superior-quality product compared to conventional clarification using synthetic polyelectrolytes (Costa *et al.*, 2014). Moringa and Aloe vera plant mucilage acted as an effective clarificant by coagulating albuminous substances during boiling, which helped

in carrying colloidal and suspended impurities to the surface as scum. The removal of this scum enhanced juice purity, thereby improving the colour and quality of jaggery. Thus, moringa clarificant contributed to better clarification efficiency and maintaining quality of the final product (Chikkappaiah *et al.*, 2017).

Hardness is an important physical property of jaggery that affects its marketing. Hardness of the jaggery samples prepared from clarificants increased significantly ($p < 0.05$) compared to control (Table 1). The results revealed that the highest hardness was recorded in jaggery prepared with 0.15% honey (23.84 kg), followed by 19.5 kg in jaggery treated with 0.2% moringa leaf extract as clarificants. In contrast, the control sample exhibited the lowest hardness (10.06 kg). These findings suggest that the use of natural clarificants enhances the hardness of jaggery, thereby improving its market value (Kumar *et al.*, 2013b). Honey contains a high concentration of reducing sugars (mainly fructose and glucose), which can influence crystallization (Weber *et al.*, 2022). When sugarcane juice boiling, the sugars in honey can promote the formation of denser and more compact crystal structures, increasing hardness compared to other clarificant used.

The colour of jaggery was evaluated using L^* , a^* , and b^* values, as presented in Table 2. A higher L^* value indicates a lighter colour, while a higher b^* value corresponds to increased yellowness (Verma *et al.*, 2019). The lowest L^* value (40.25) was recorded for the control sample prepared without clarificants whereas the highest L^* value (56.95) was observed in jaggery treated with 0.2% moringa leaf extract as a natural clarificant. The maximum a^* value (96.47) was noted in jaggery samples treated with 0.1%, 0.15%, and 0.2% moringa leaf extract, as well as in the control sample. In contrast, the lowest a^* value (75.76) was found in jaggery prepared with 0.05% moringa leaf extract. The maximum b^* value of 100.23 was found for moringa leaf extract of

Table 1: Physico-chemical properties of jaggery produced with natural clarificants

Clarificants (%)	Reducing sugars (%)	Non-reducing sugars (%)	Hardness (kg)	Moisture (%)
Control	10.98 \pm 0.95 ^a	81.19 \pm 1.25 ^f	10.06 \pm 0.87 ^a	4.19 \pm 0.08 ^b
Aloe vera juice				
0.05	11.31 \pm 0.96 ^d	85.81 \pm 1.59 ^b	16.77 \pm 0.87 ^b	3.90 \pm 0.05 ^c
0.1	11.31 \pm 0.92 ^d	85.73 \pm 1.67 ^b	16.84 \pm 0.98 ^b	3.15 \pm 0.02 ^f
0.15	11.65 \pm 0.88 ^c	83.37 \pm 1.68 ^d	12.77 \pm 0.94 ^d	3.76 \pm 0.05 ^e
0.2	12.40 \pm 0.46 ^a	82.51 \pm 1.98 ^e	17.25 \pm 0.89 ^d	3.09 \pm 0.03 ^f
Moringa leaf extract				
0.05	10.39 \pm 0.87 ^a	87.88 \pm 1.59 ^a	11.25 \pm 0.67 ^b	3.29 \pm 0.02 ^e
0.1	10.68 \pm 1.00 ^f	87.85 \pm 1.72 ^a	12.32 \pm 0.78 ^d	4.36 \pm 0.08 ^b
0.15	10.98 \pm 1.20 ^e	83.99 \pm 1.42 ^d	18.52 \pm 0.97 ^c	3.27 \pm 0.03 ^e
0.2	11.31 \pm 0.74 ^d	83.19 \pm 1.68 ^d	19.50 \pm 0.98 ^b	3.48 \pm 0.05 ^d
Honey				
0.05	11.90 \pm 0.92 ^b	84.60 \pm 1.28 ^c	14.45 \pm 0.46 ^e	3.04 \pm 0.02 ^f
0.1	11.02 \pm 0.93 ^a	83.50 \pm 1.42 ^d	10.53 \pm 0.53 ^f	3.41 \pm 0.05 ^d
0.15	10.99 \pm 0.89 ^e	82.73 \pm 1.98 ^e	23.84 \pm 0.89 ^a	3.80 \pm 0.03 ^e
0.2	11.90 \pm 0.96 ^b	82.49 \pm 1.78 ^e	13.64 \pm 0.48 ^f	6.38 \pm 0.08 ^a

All the values are means of three replicates with standard deviation, Alphabetic letters represent statistical difference within the columns ($p < 0.05$).

Table 2: Color values of jaggery prepared using aloe vera juice, moringa leaf extract and honey.

Clarificant (%)	L* value	a* value	b* value	ΔE
Control	40.25±0.83 ^g	-96.47±1.24 ^d	-64.47±0.84 ^b	=
Aloe vera juice				
0.05	43.88±0.95 ^e	-86.11±1.79 ^a	-78.58±0.98 ^c	0.12
0.1	45.78±0.98 ^d	-89.88±1.47 ^b	-90.82±1.03 ^f	14.23
0.15	49.89±1.06 ^c	-84.23±2.42 ^a	-80.47±0.94 ^d	5.88
0.2	52.16±0.78 ^b	-84.23±2.04 ^a	-79.52±0.79 ^c	21.36
Moringa leaf extract				
0.05	45.60±0.94 ^d	-75.76±0.97 ^b	-69.17±1.24 ^a	26.13
0.1	49.85±0.89 ^c	-96.47±1.04 ^d	-100.23±0.99 ^g	9.47
0.15	55.25±0.86 ^a	-96.47±1.48 ^d	-88.94±0.96 ^b	19.06
0.2	56.95±0.99 ^a	-96.47±1.40 ^d	-100.23±0.95 ^g	13.5
Honey				
0.05	40.86±1.03 ^f	-91.76±0.99 ^c	-83.29±1.02 ^e	12.38
0.1	41.98±0.99 ^f	-92.70±1.54 ^c	-82.35±0.92 ^e	13.19
0.15	43.99±0.95 ^e	-92.70±1.78 ^c	-85.17±1.40 ^b	8.76
0.2	45.60±0.74 ^d	-89.88±1.43 ^b	-85.17±1.52 ^b	6.15

All the values are means of three replicates with standard deviation. Alphabetic letters represent statistical difference within the columns ($p < 0.05$).

Table 3: Thickness, area, water vapor transmission rate and permeability of packaging materials used for storage studies of jaggery prepared using natural clarificants

Materials	Thickness (micron)	Area (m ²)	WVTR (kg water/day×m ²)	Permeability (kg water/day×m ² ×Pa)
LDPE	87.5	0.0337	0.000003375	2.48907E-05
Aluminium foil	12	0.0357	0.00000714	5.26576E-05
2.5-layer metalized polyester	47	0.0294	0.00000588	4.33651E-05
3-layer metalized polyester	59	0.054	0.0000054	3.98251E-05

0.1 and 0.2 % and the minimum b* value of 64.47 was found for control (jaggery prepared without addition of clarificants). The maximum colour change (ΔE) in jaggery was observed with the use of 0.05 % moringa leaf extract. The colour values suggested that addition of natural clarificants improved the colour of jaggery as indicated by higher L* and b* values of jaggery prepared using clarificants compared to control. This could possibly be due to the removal of impurities through scum due to addition of clarificants. Similar results were reported by Patil *et al.* (2005), who observed that both synthetic and herbal clarificants were effective in removing a maximum amount of scum, thereby improving the colour of jaggery. Kumar *et al.* (2022) also reported that the optimized mixture of clarificants comprising 0.5% okra stem, 0.1% soybean seeds, and 0.4% fenugreek seeds was the most effective, yielding an optimized jaggery recovery of 12.16% and scum removal of 6.58%. Ragavan *et al.* (2011) reported that okra mucilage and soybean seed meal (40–45 g 100 ml⁻¹) significantly contributed to the removal of scum, reduction of reducing sugars, and improvement of jaggery colour. They also noted that *Hibiscus vitifolius* extract served as a natural clarifying agent in gur production, yielding superior quality compared to chemical clarifiers. It effectively settled impurities (3 ppm extract \approx 1 ppm chemical) and exhibited a bleaching action that removed unwanted colours, producing golden-yellow gur while reducing production costs.

The moisture content of the jaggery prepared with different natural clarificants ranged from 3.04 to 6.38% (w.b) (Table 1). The lowest moisture content (3.04%) was recorded in jaggery prepared with 0.05% honey, followed by 3.27% in the sample treated with 0.15% moringa leaf extract as a clarificant. In contrast, the highest moisture content (6.38%) was observed in jaggery prepared with 0.2% honey. All samples exhibited moisture content below 6%, indicating good-quality jaggery. A reduction in moisture content was associated with increased hardness of the jaggery. Jaggery with high moisture levels (>6%) provide favourable environment for growth of various types of bacteria and fungi some of which are pathogenic (Oliveira *et al.*, 2006; Owen, 1977; Singh *et al.*, 2009).

Water vapour transmission rate (WVTR) and water vapor permeability of packaging material is summarized in Table 3. The results suggested that LDPE exhibited the lowest permeability (2.49×10^{-5} kg m⁻² day⁻¹ Pa⁻¹), followed by 3-layer metalized polyester and 2.5-layer metalized polyester and aluminium foil. Change in hardness of jaggery prepared with different natural clarificants stored at 25 °C in four different packaging materials (LDPE, aluminium foil, 2.5-layer metalized polyester, 3-layer metalized polyester) are shown in Fig. 1. The maximum change in hardness (0.22 N) was observed for jaggery packed in aluminium foil and the minimum change in the hardness (0.008 N) was

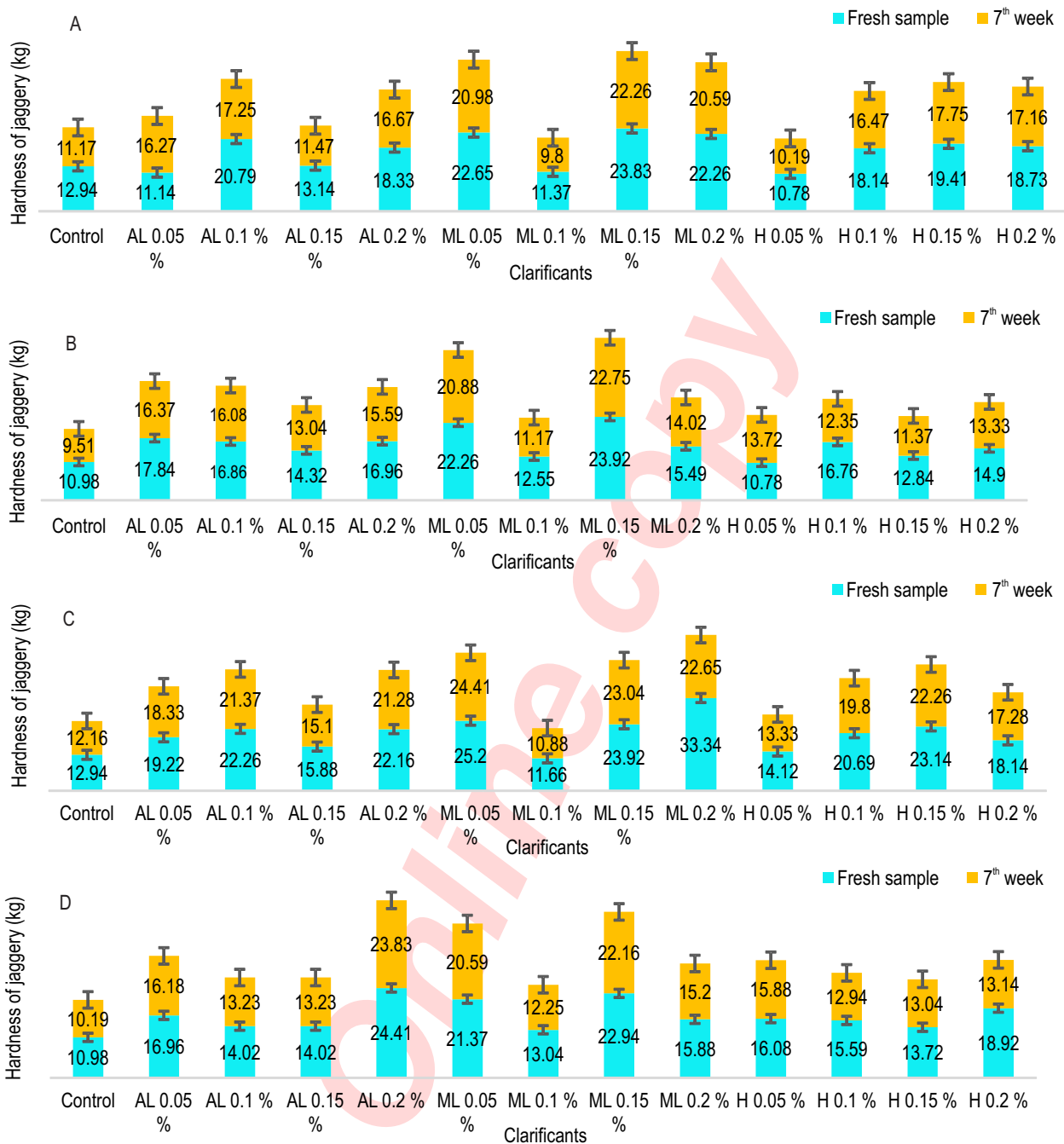


Fig. 1: Change in Hardness of jaggery stored in (A) Aluminium foil, (B) LDPE, (C) 2.5-Layer metallized polyester and (D) 3-Layer metallized polyester.

observed for jaggery packed in 3-layer metallized polyester. Hardness showed decreasing trend during the storage period in aluminium foil and LDPE packaging material. Storage of jaggery samples in 2.5 and 3-layer metallized polyesters helped in maintaining the desirable hard texture while storage in the LDPE and aluminium foil materials led to moisture gain by jaggery thereby, loosing its hard texture, making it undesirable. Changes

in non-reducing sugar contents in solid jaggery packed in aluminium foil, LDPE, 2.5 and 3-layer metallized polyester over entire storage period of seven weeks is presented in Fig. 2. The decrease in non-reducing sugars was lowest in jaggery stored in 3-layer metallized polyester packaging (0.30%), followed by 2.5-layer metallized polyester (0.28%) and LDPE (0.55%), compared to aluminium foil packaging (0.70%). This trend may be attributed

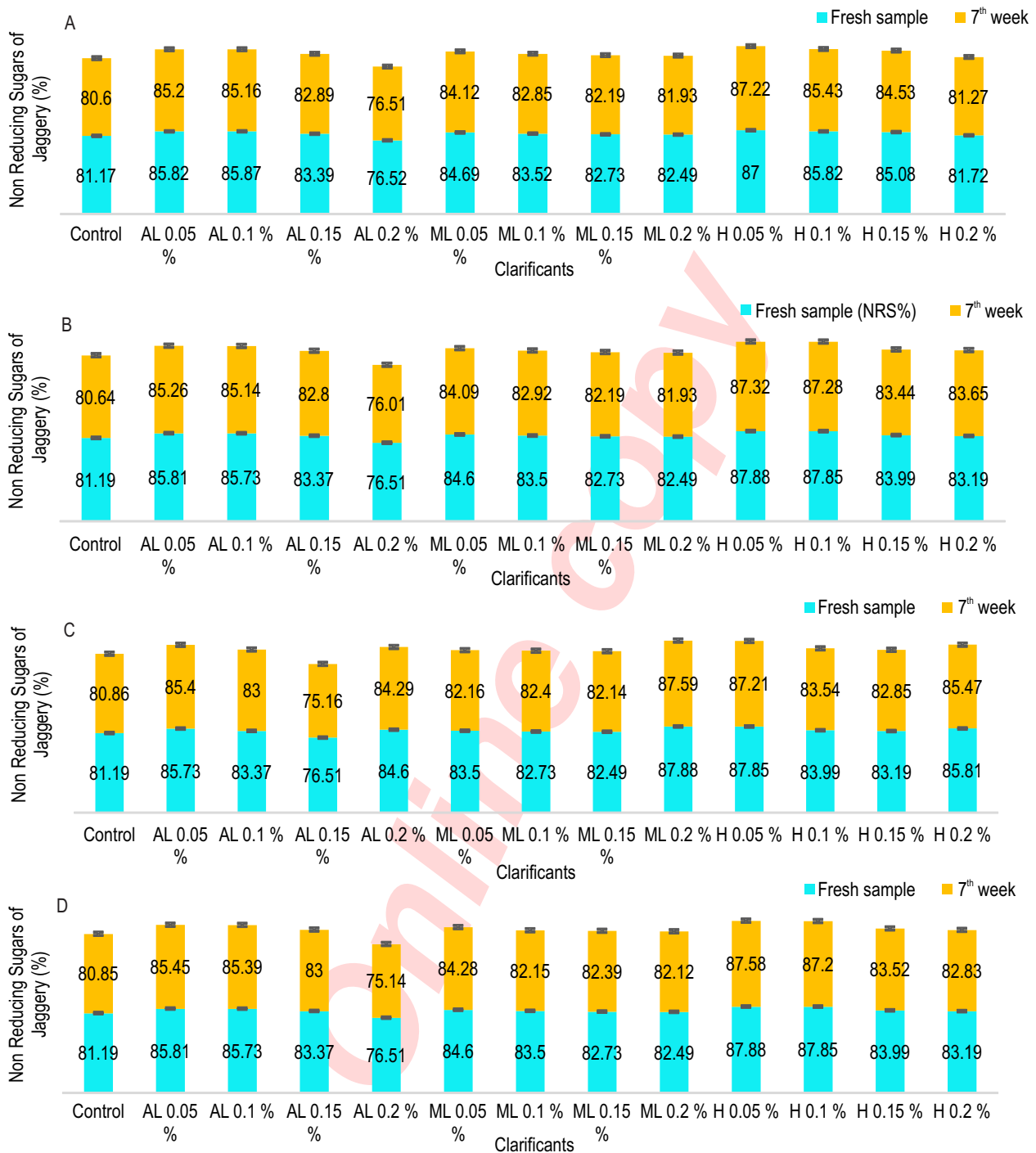


Fig. 2: Change in non-reducing sugars of jaggery stored in (A) Aluminium foil, (B) LDPE, (C) 2.5-Layer metalized polyester and (D) 3-Layer metalized polyester.

to the lower moisture permeability of the multilayer packaging materials, which helps in better preservation of sugar content. A decrease in non-reducing sugar content of jaggery during storage may be due to the metabolism of non-reducing by microorganisms, responsible for spoilage of jaggery. The

changes in reducing sugar content of solid jaggery packed in aluminium foil, LDPE, 2.5-layer metallized polyester, and 3-layer metallized polyester during the storage period are shown in Fig. 3. The increase in reducing sugars was lowest in the 3-layer metallized polyester (0.50%), followed by 2.5-layer metallized

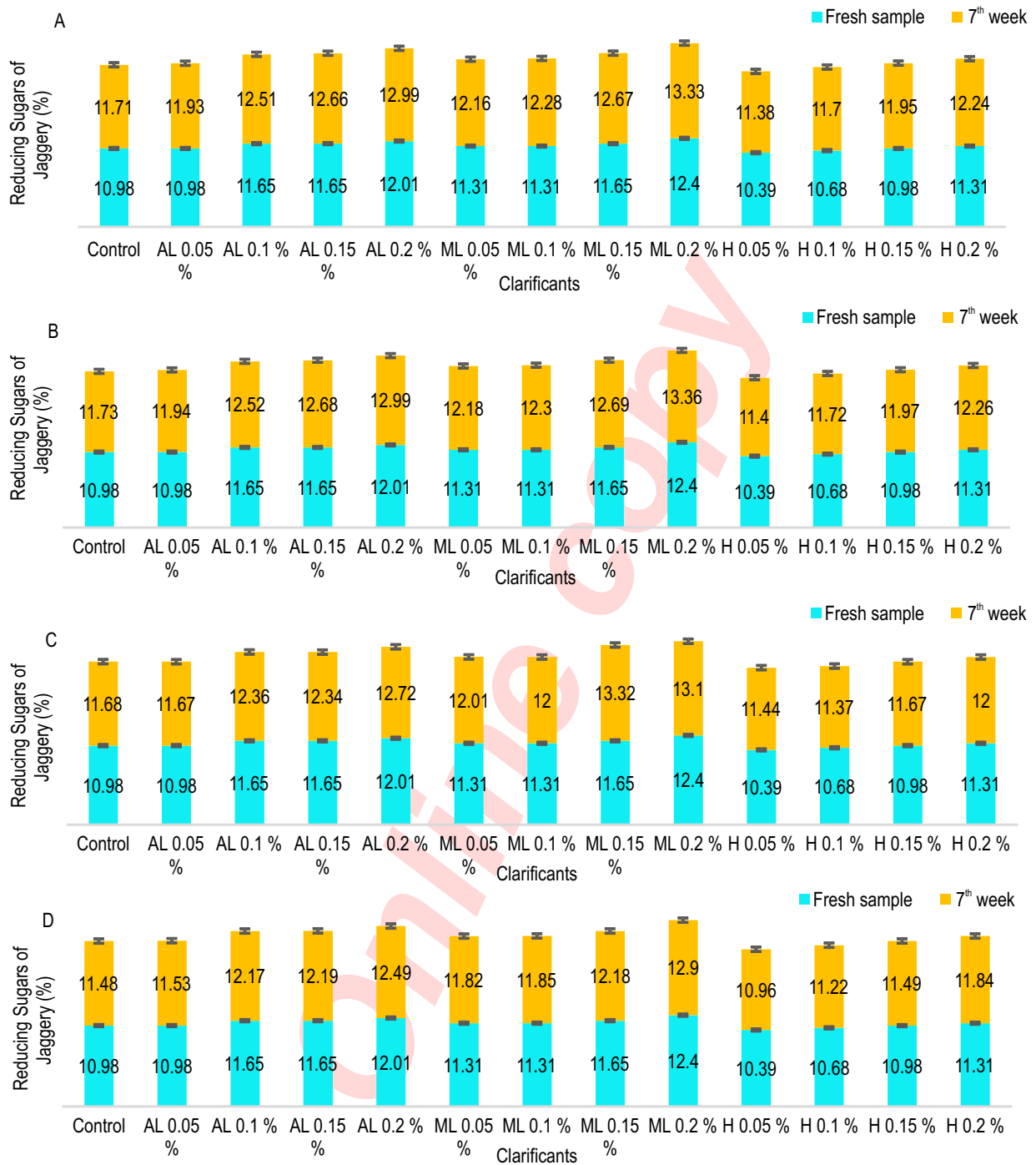


Fig. 3: Change in reducing sugars of jaggery stored in (A) aluminium foil, (B) LDPE, (C) 2.5-layer metalized polyester and (D) 3-layer metalized polyester.

polyester (0.70%) and LDPE (0.90%), while the maximum increase (1.0%) was observed in aluminium foil packaging, which corroborates with the previous findings (Chand et al., 2012; Kumar et al., 2013a,b; Mandal et al., 2006). Moisture plays a vital role in maintain the shelf-life. Change in moisture content of solid

jaggery packed in aluminium foil, LDPE packaging material, 2.5-layer metalized polyester and 3-layer metalized polyester over storage period from initial day to 7 weeks is presented in Fig. 4. During storage, the increase in moisture content was minimum in jaggery sample packed in 3-layer metalized polyester (0.2%)

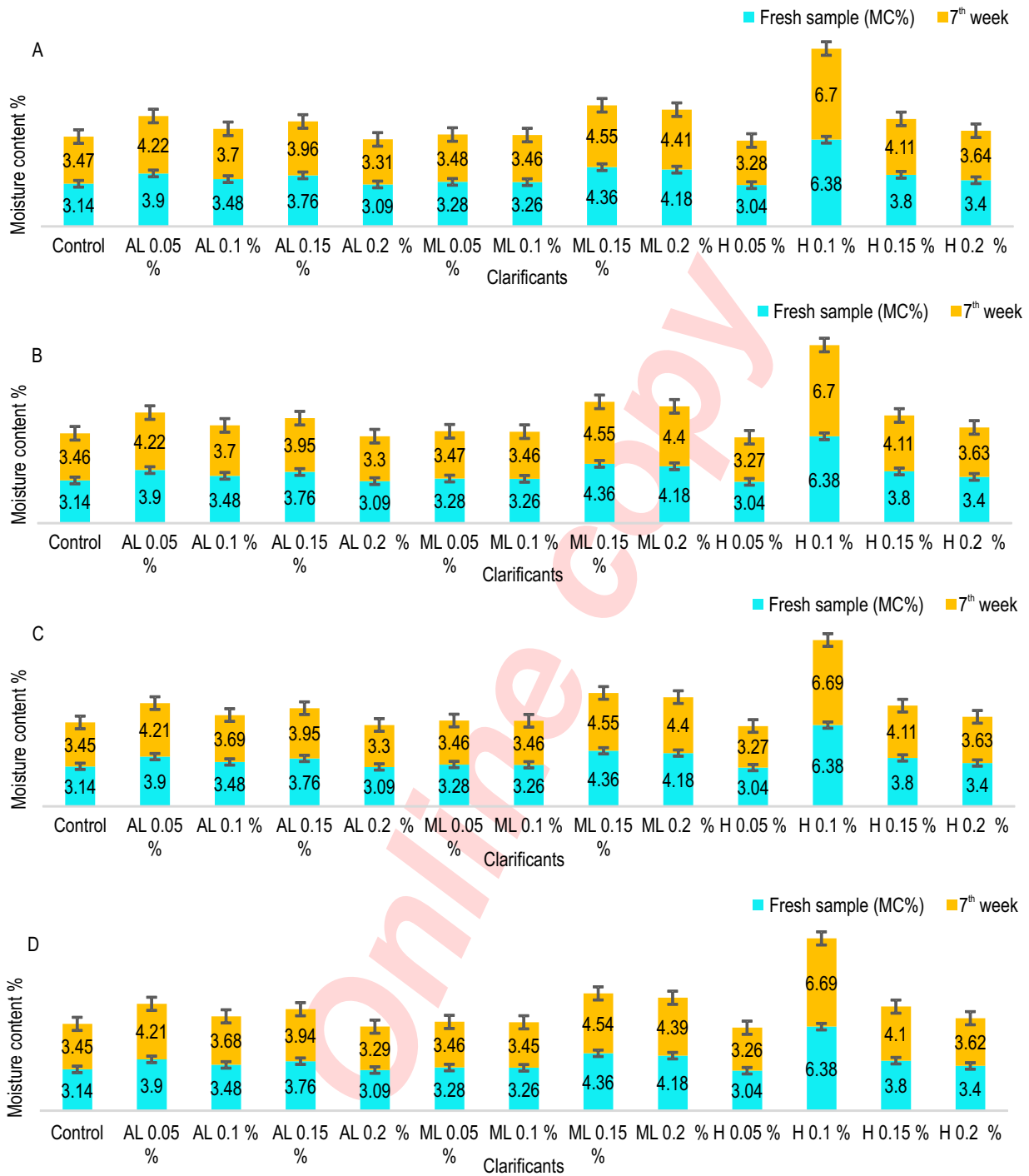


Fig. 4: Change in moisture content of jaggery stored in (A) aluminium foil, (B) LDPE, (C) 2.5-layer metalized polyester and (D) 3-layer metalized polyester.

followed by 2.5-layer metalized polyester (0.30%) and LDPE packaging material (0.35%) compared to aluminium foil packaging material (0.40%) during storage period for 7 weeks. The L^* represents the brightness value. All four packaging materials (aluminium foil, LDPE packaging material, 2.5-layer

metalized polyester and 3-layer metalized polyester) showed decreasing trend in L^* value (Fig. 5), however, the reduction in L^* value was low in 3-layer metalized polyester (0.20) followed by 2.5-layer packaging material (0.25), LDPE packaging material (0.30) and aluminium foil (0.35).

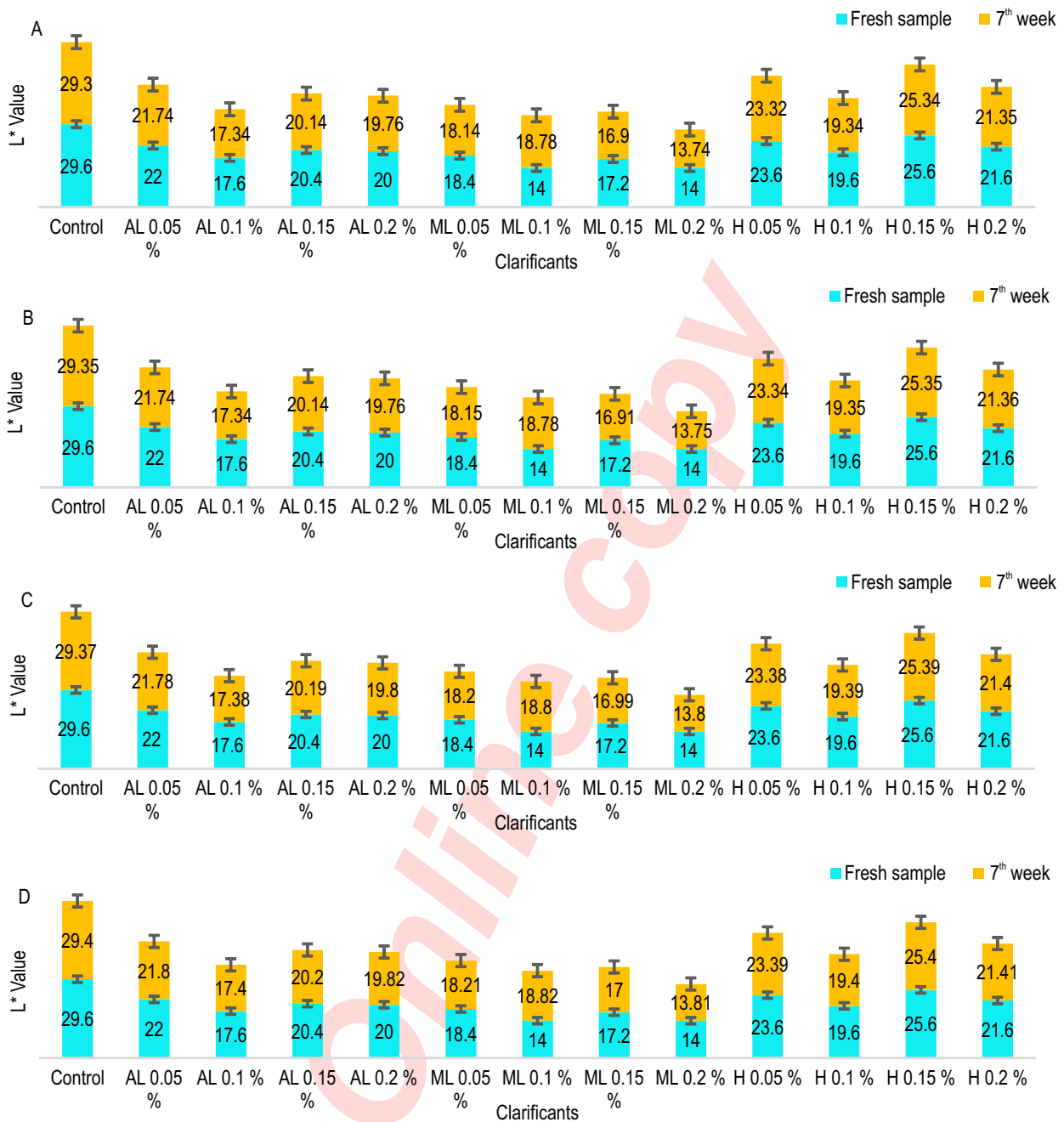


Fig. 5: Change in colour of jaggery stored in (A) aluminium foil, (B) LDPE, (C) 2.5-layer metalized polyester and (D) 3-layer metalized polyester.

A similar study on storage of jaggery in airtight plastic and glass containers showed that there was no significant change in the quality parameters of jaggery, except for colour, which was maintained brighter in airtight glass containers (Uppal *et al.*, 2002). The results of storage studies revealed that 3 layer metalized polyester pouches were suitable for storing jaggery prepared using natural clarificants for 7 weeks without significant change in the quality parameters such as hardness, non-reducing

sugars, reducing sugar, moisture content and colour. The order of preference of packaging material for the storage of jaggery next to 3 layer metalized polyester pouches was 2.5-layer packaging material > LDPE packaging material > aluminium foil. Sensory scores of jaggery samples with respect to quality attributes namely, colour, taste, flavour and texture. The samples S₁, S₂, S₃, S₉ and S₁₃ had higher scores for colour, S₁, S₂, S₃, S₄, S₁₃ and S₁₇ for taste, S₁, S₂, S₃ and S₁₃ for flavour; and S₁, S₂, S₃, S₉ and S₁₃ for

Table 4: Quality ranking subset values of jaggery prepared with clarificants

Quality	Weightage average	S ₁	S ₂	S ₃	S ₄	S ₅	S ₆	S ₇	S ₈	S ₉
Colour	0.26	0.24	0.24	0.26	0.25	0.26	0.25	0.26	0.26	0.26
Taste	0.28	0.26	0.25	0.23	0.24	0.27	0.25	0.24	0.24	0.24
Flavour	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.22	0.22	0.23
Texture	0.23	0.23	0.23	0.21	0.23	0.23	0.23	0.23	0.23	0.23
	Ranking	V	VII	XIII	IX	IV	VIII	X	X	IX
Quality	Weightage average	S ₁₀	S ₁₁	S ₁₂	S ₁₃					
Colour	0.26	0.25	0.26	0.26	0.25					
Taste	0.28	0.28	0.27	0.27	0.25					
Flavour	0.23	0.19	0.23	0.23	0.23					
Texture	0.23	0.23	0.22	0.21	0.23					
	Ranking	I	II	III	VI					

Table 5: Vitamin and, C contents in jaggery prepared using aloe vera juice, moringa leaf extract and honey at 0.1% concentration

Clarificant	Vitamin A (mg 100g ⁻¹ of jaggery)	Vitamin C (mg 100g ⁻¹ of jaggery)
Control	3.2±0.5 ^b	7.0±0.2 ^c
Aloe vera juice	4.9±0.3 ^a	7.9±0.3 ^b
Moringa leaf extract	5.2±0.5 ^a	8.8±0.5 ^a
Honey	0.97±0.3 ^c	1.75±0.1 ^d

Alphabets letters in the superscripts denote that the mean values are statistically different with in the column at p<0.05

texture. The judgement membership function (JMF) values and the average of weightage obtained for each quality attribute were compared. The weightage average value of colour (0.249) was maximum, followed by flavour (0.245), taste (0.235) and texture (0.228). Preference order of quality attributes for solid jaggery prepared with natural clarificants in general showed the followed trend: colour > flavour > taste > texture. FMF (fuzzy membership function) and NFMF (normalized fuzzy membership function) were calculated and used for obtaining judgement membership function (JMF). Comparing the weightage average of quality attributes and JMF obtained for samples, the quality ranking subset value was given by assigning minimum of these two values (Table 4). The comparison suggested that out of four jaggery samples prepared using moringa leaf extract (0.05, 0.1, 0.15 and 0.2 %), three samples, i.e. S₁₀, S₁₁ and S₁₂ having 0.1,

0.15 and 0.2% moringa leaf extract ranked top three. These results indicate that using moringa leaf extract as clarificants can improve the sensory attributes of jaggery, thereby increasing their acceptance over jaggery prepared through conventional method. Results of vitamin (A and C) analysis of jaggery samples are given in Table 5. Jaggery prepared without clarificant contained vitamin A and C at concentrations of 3.2 mg and 7.0 mg per 100g of sample respectively. The maximum concentration of vitamin A and C is observed in moringa leaf extract at 0.1% i.e. 5.2 and 8.8 mg per 100g respectively. The values of these vitamins in jaggery were similar to that of the values reported in the literature (Hirpara, 2020; Singh *et al.*, 2013). Vitamins A and C contents increased significantly in jaggery prepared using moringa leaf extract compared to that of control and the increase was also observed with the use of aloe vera juice (Mahmood, 2010; Sharrif and Res, 2011). Moreover, the maximum retention of vitamins A and C at high temperatures of processing were reported previously (Leskova, 2006). Therefore, the health benefits of jaggery can be improved by using moringa and aloe vera.

Since the above studies showed that the moringa leaf extract was an effective clarificant comparison to other natural clarificants used in the present study, its concentration was optimized using Design Expert software by setting goals and importance given to them as mentioned in Table 6. The perusal of data showed that the moringa leaf concentration had a negative effect on reducing sugars and positive effect on non-reducing sugars and hardness. Also, with increase in the concentration of moringa leaf extract, the brightness of jaggery

Table 6: Constraints, goal, criteria for optimization and importance and optimized conditions

Constraints	Goal	Lower Limit	Upper Limit	Importance	Solution
Moringa leaf extract (%)	in range	0	0.2	3	0.168
Reducing sugars (%)	Minimize	10.99	11.98	3	11.08
Non reducing sugar (%)	Maximize	81.99	85.49	3	84.96
Hardness (kg)	Maximize	10.06	19.29	3	17.72
L*	Maximize	40.18	58.9	3	55.99
Desirability					0.864

exponentially. The optimization gave solution of moringa leaf concentration of 0.168 % contributing to reducing sugars of 11.08%, non-reducing sugars of 84.96%, hardness of 17.72 kg and L* value of 55.99 with a desirability of 0.864 (Table 6). Jaggery prepared using clarificants such as aloe vera juice, moringa leaf extract and honey were found to have good quality with respect to the contents of sucrose, reducing sugars and physical properties.

Moringa leaf and Aloe vera significantly increased vitamins A and C in jaggery. The suitable packaging material for storing jaggery prepared using natural clarificants was found to be 3-layer metalized polyester pouches. Among the clarificants used in the present study, moringa leaf extract showed significant improvement in sensory attributes, thereby, increased overall acceptance of jaggery compared to control and the optimized concentration of 0.168%. The present study demonstrated the effective utilization of aloe vera, moringa leaf and honey as natural clarificants instead of hazardous chemicals in the production of jaggery to improve its marketing quality with additional health benefits.

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