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Effect of different pre-treatments on the drying kinetics of osmotic dehydrated cauliflower

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Abstract
This study investigated the effect of different pre-treatments and packaging materials on the drying kinetics and storage quality of osmotically dehydrated cauliflower (Brassica oleracea var. botrytis). Fresh, uniform cauliflower florets were subjected to four pre-treatment methods: control (untreated), blanching (100 °C for 3 min), citric acid steeping (0.25% for 10 min), and potassium metabisulphite (KMS) steeping (0.25% for 10 min). Samples were osmotically dehydrated in sodium chloride (NaCl) brine at concentrations of 1%, 2%, and 3%, using a sample-to-solution ratio of 1:4 at 27±2 °C for 4 hours, followed by tray drying at 60 °C until constant weight. Dried samples were packaged in aluminum foil and high-density polyethylene (HDPE) pouches and stored at ambient temperature (25±2 °C) for 120 days. Drying kinetics parameters sample weight, moisture content, moisture loss, drying rate, and moisture ratio were analyzed along with physicochemical (pH, titratable acidity, optical density, ash, ascorbic acid) and sensory attributes at intervals of 0, 30, 60, 90, and 120 days. Results indicated that blanching and citric acid treatments significantly enhanced drying efficiency, reduced drying time, and improved retention of ascorbic acid, color, and sensory scores compared to control and KMS treatments. The drying process followed the classical two-phase pattern, with an initial constant-rate period followed by a falling-rate period. Regression models for drying characteristics exhibited high R^2 values (>0.90) in most cases, confirming strong predictive capability. During storage, aluminum foil packaging maintained superior product quality with lower moisture uptake and higher nutrient retention than HDPE. The optimized process blanching or citric acid pre-treatment, osmotic dehydration in 2-3% brine, tray drying at 60 °C, and storage in aluminum foil proved effective for prolonging shelf life and enhancing marketability.

Keywords: Osmotic dehydration, pre-treatment, drying kinetics, cauliflower, storage quality

1. Introduction

Vegetables constitute a vital component of human nutrition, providing essential vitamins, minerals, dietary fibers, and bioactive compounds that play pivotal roles in maintaining health and preventing chronic diseases. Among these, cauliflower (Brassica oleracea var. botrytis), a member of the Brassicaceae family, has gained prominence due to its nutritional richness, economic significance, and global adaptability. The worldwide production of cauliflower has been increasing steadily, with China and India contributing over 70% of the total supply (FAO, 2023) [7]. It is particularly valued for its low-calorie, high-nutrient profile, offering significant amounts of vitamins C, K, B-complex, minerals such as calcium, potassium, magnesium, and dietary fiber, along with health-promoting phytochemicals like glucosinolates and sulforaphane. These compounds have been extensively studied for their antioxidant, anti-inflammatory, antidiabetic, and anticancer properties, linking cauliflower consumption to improved health outcomes (Li *et al.*, 2022; Singh *et al.*, 2023) [14, 26]. Cauliflower's global demand is underpinned by its versatility in culinary applications and its recognition as a functional food. Rich in ascorbic acid, folate, and dietary antioxidants, cauliflower contributes to the reduction of oxidative stress, improved immunity, and chronic disease prevention (Azeem *et al.*, 2023) [3]. The vegetable's glucosinolates degrade into isothiocyanates like sulforaphane, compounds associated with anticarcinogenic effects, making cauliflower a recommended dietary component for health-conscious consumers (Singh *et al.*, 2023) [26]. After harvest, ongoing respiration accelerates senescence, chlorophyll degradation, and nutrient loss, with visible quality deterioration such as wilting, browning, and off-flavor development. Inadequate cold chain facilities in developing countries worsen these challenges, resulting in post-harvest losses exceeding 30% (Gupta *et al*., 2022) [10]. Studies have demonstrated that optimized blanching conditions can significantly improve the quality of dehydrated cauliflower. Recent advancements like microwave and ultrasound-assisted blanching have further reduced processing times, minimized nutrient leaching, and improved overall energy efficiency (Yuan *et al*., 2022) [31]. Thus, blanching remains an essential pre-treatment for maintaining the sensory and nutritional integrity of dehydrated cauliflower. Osmotic dehydration (OD) involves immersing cauliflower florets in a hypertonic solution (commonly sucrose, salt, or their combinations), which induces water removal by osmosis while allowing selective solute infusion. OD offers multiple benefits over conventional drying, including reduction in water activity, inhibiting microbial growth, better retention of color, flavor, and nutrients owing to the lower thermal load, minimized shrinkage and improved texture in the final dried product, and enhanced rehydration capacity, making products more appealing to consumers (Mahapatra *et al*., 2022) [15]. Studies have shown that storing dehydrated cauliflower in low-density polyethylene (LDPE) bags at room temperature can maintain acceptable quality for up to four months (Mohanta, 2008) [16]. Packaging serves as a critical barrier against moisture gain, oxidative reactions, and microbial contamination, ensuring the longevity and safety of dehydrated cauliflower. Traditional materials such as LDPE, polypropylene (PP), and aluminum laminates are widely used due to their durability and cost-effectiveness. However, recent advancements in active and intelligent packaging offer enhanced protection and real-time quality monitoring. For instance, oxygen scavengers, antimicrobial films, and biodegradable alternatives are gaining traction for eco-friendly preservation (Saini *et al*., 2023; EPA, 2023) [24]. Optimizing packaging for mechanical strength, barrier properties, and sustainability is essential to ensure product integrity during storage, handling, and transportation, particularly in hot and humid climates. Cauliflower's high perishability, combined with seasonal overproduction and limited cold storage infrastructure, leads to significant post-harvest losses. Traditional preservation techniques often compromise color, texture, and nutritional value, limiting consumer acceptance. The specific objectives are to investigate the mass transfer kinetics of osmotic dehydration under varying concentrations, temperatures, and immersion times; evaluate the impact of blanching and other pre-treatments on drying characteristics and quality parameters (color, texture, rehydration ratio, and nutrient retention); assess the storage stability of dehydrated cauliflower packed in different materials (LDPE, biodegradable, and advanced active packaging); and recommend optimized processing and packaging protocols to minimize post-harvest losses and improve economic returns for farmers and processors. Cauliflower is highly nutritious but extremely perishable, leading to post-harvest losses exceeding 30% in developing countries due to inadequate cold storage. Traditional preservation methods are costly and unsuitable for small farmers, creating a need for low-cost, effective alternatives. Osmotic dehydration combined with pre-treatments like blanching or citric acid can enhance drying efficiency, nutrient retention, and sensory quality. Packaging plays a crucial role in maintaining quality, with aluminum foil offering superior protection compared to conventional materials. This study is justified to optimize pre-treatments, dehydration parameters, and packaging to extend shelf life, reduce losses, and improve marketability.

2. Material and Methods

2.1 Experimental Location

The experiment of different pre-treatments and drying kinetics of osmotically dried cauliflower, storage quality of cauliflower and packaging was carried out at the Department of Process and Food Engineering, (College of Technology), Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut, Uttar Pradesh.

2.2 Raw Material Procurement and Preparation

Fresh and mature cauliflower were procured from the local market, ensuring the absence of visible blemishes, mechanical damage, or microbial infection. The curds were washed thoroughly under running water to remove dirt and adhered foreign matter, and then manually cut into slice form to minimize variability in mass transfer during dehydration (Fellows, 2009) [8].

2.3 Experimental Design and Treatments

The experimental work was designed under a full factorial randomized design with three replications to study the influence of pre-treatments, brine concentration, and packaging materials on osmotic dehydration characteristics and storage quality. Four pre-treatment methods were evaluated: control (untreated), blanching at 100 °C for 3 minutes, steeping in 0.25% citric acid solution for 10 minutes, and steeping in 0.25% potassium metabisulphite (KMS) solution for 10 minutes. The treated samples were subjected to osmotic dehydration using sodium chloride (NaCl) brine solutions at 1%, 2%, and 3% concentrations, with a sample-to-solution ratio of 1:4 (Chandra & Das, 2008) [5].

2.4 Osmotic Dehydration

The osmotic process was conducted at room temperature for a fixed duration of 4 hours to facilitate maximum water loss and solid gain (Chandra & Das, 2008) [5].

2.5 Drying Process

The Post osmotic treatment, samples were tray-dried at a controlled temperature of 60 °C until constant weight was attained, thus reducing moisture to safe storage levels (Chandra & Das, 2008) [5].

2.6 Packaging and Storage

Dried samples were packaged in two types of packaging materials aluminum foil pouches and high-density polyethylene (HDPE) pouches to study the impact of packaging on product stability. The packaged samples were stored at ambient room temperature for a period of 120 days, with observations recorded at 0, 30, 60, 90, and 120 days.

2.7 Quality Evaluation

Quality evaluations were carried out immediately after drying and at subsequent storage intervals to monitor changes in physicochemical, functional, and sensory attributes. Drying kinetics were evaluated in terms of initial and final moisture content, moisture ratio, and drying rate (Fellows, 2009) [8].

2.8 Statistical Analysis

All experiments were carried out in triplicate, and the resulting data were statistically analyzed using analysis of variance (ANOVA) with Design-Expert software (v.13) to determine significant differences among treatments at a 5% level of significance ($p \leq 0.05$).

2.9 Optimization Criteria

Optimization criteria included maximum water removal during osmotic dehydration, retention of ascorbic acid and sensory attributes, and maintenance of quality during the 120 days storage period (Chandra & Das, 2008) [5].

3. Result and Discussions

3.1 Drying Kinetics of Cauliflower

The drying behavior of cauliflower was studied at 60 °C using a tray dryer under different pre-treatments: blanching, citric acid, and KMS. Key parameters like initial and final moisture content, drying rate, moisture loss, and moisture ratio were analyzed to evaluate the impact of these treatments on drying efficiency.

3.1.1 Drying Kinetics of Control Cauliflower Samples in Tray Dryer at 60 °C

Figure 3.1 shows a consistent reduction in the weight of control cauliflower from 2000.0 g to 420.8 g over 13 hours at 60 °C, indicating effective and progressive moisture loss. The initially steep slope reflects rapid evaporation of surface moisture, which gradually transitions into a slower drying phase as internal bound moisture is removed a typical shift from constant to falling rate drying. The associated ANOVA confirms the model's high significance, with an F-value of 314.60 and a p-value < 0.05 for time (Factor A), suggesting a strong influence. The model demonstrates excellent accuracy, as reflected in its low standard deviation (100.21), mean (1043.14), and C.V. (9.61%). A high R^2 (0.9633), along with adjusted (0.9602) and predicted R^2 (0.9436), and an adequate precision of 40.447, confirm the model's robustness and predictive power. Similarly, Figure 3.2 highlights a steady decline in dry basis, moisture content dropped significantly from 1729.49% to 220.3%, due to the constant dry matter. The corresponding model again shows high validity ($F = 284.08$, $p<0.0001$), with $R^2 = 0.9595$, adjusted $R^2 = 0.9561$, predicted $R^2 = 0.9378$, and an adequate precision of 38.435, confirming its strong predictive capability during the drying process of untreated cauliflower.

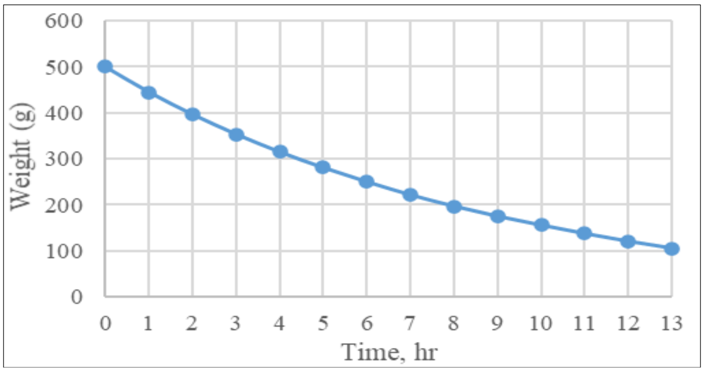

Fig 3.1: Variation in Sample Weight of Control Cauliflower During Drying at

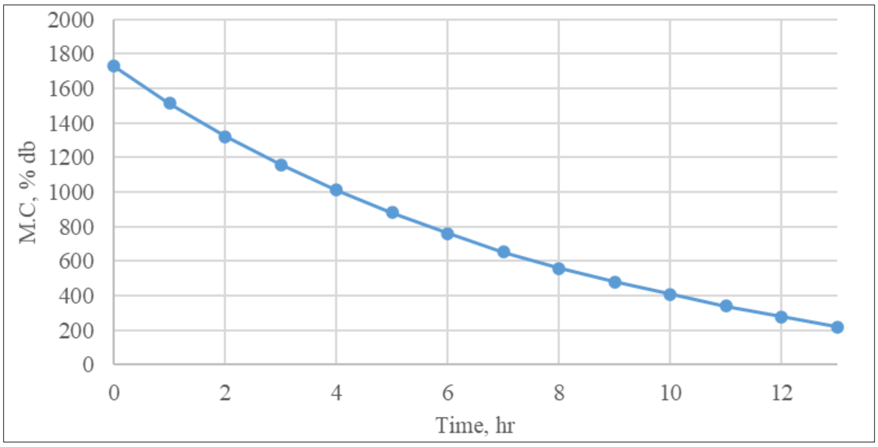

Fig 3.2: Change in Moisture Content (Dry Basis) of Control Cauliflower During Drying

Figure 3.3 reveals that moisture loss occurred rapidly during the initial stage, reaching a peak of 55 grams in the first hour, driven by the easy removal of free water. As drying progressed, the rate decreased markedly, reflecting the shift to bound water removal, which is more energy-intensive. The curve's leveling at the end indicates that the sample neared its equilibrium moisture content. However, statistical analysis shows that the model describing this behavior is not significant at the 5% level, with a Model F-value of 3.67 and a p-value of 0.0797. The low R^2 (0.2340), adjusted R^2 (0.1702), and negative predicted R^2 (-0.3118) demonstrate limited explanatory and predictive capability. Although the adequate precision value of 4.366 meets the minimum threshold, the high coefficient of variation (47.64%) points to substantial data variability, suggesting the model may need refinement or simplification for better accuracy.

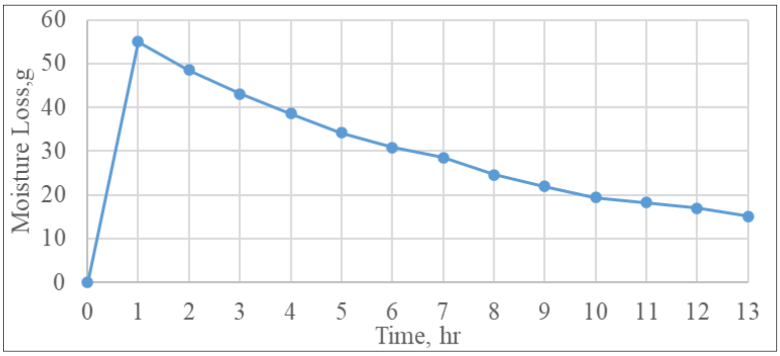

Fig. 3.3: Moisture Loss of Control Cauliflower as a Function of Drying Time

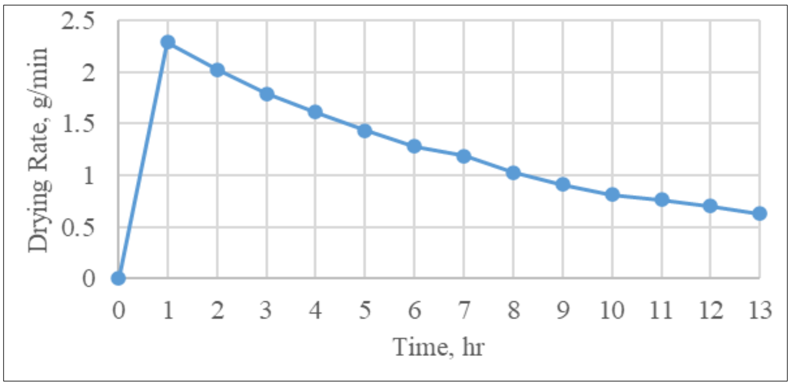

Fig 3.4: Drying Rate of Control Cauliflower with Respect to Time

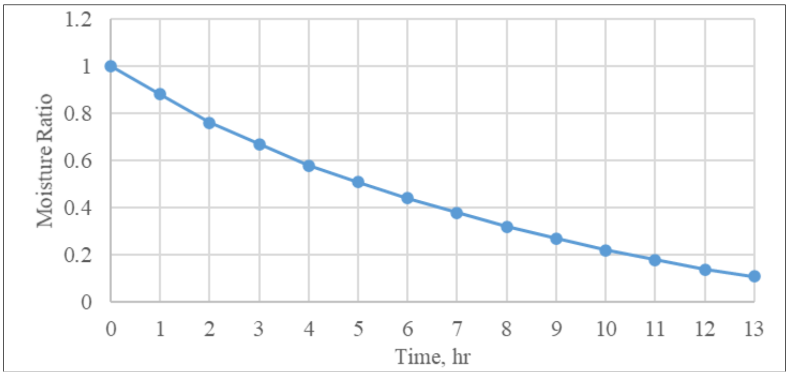

Fig 3.5: Moisture Ratio vs. Time During Drying of Control Cauliflower

Figure 3.4 presents the drying rate of control cauliflower, which follows classical drying behavior. The drying rate peaks at 2.29 g/min in the first hour, reflecting rapid moisture removal during the initial phase when free water is readily available on the surface. As drying continues, the rate steadily declines due to reduced surface moisture and the growing influence of internal diffusion, signifying the falling rate period typical in food dehydration processes. However, the model representing this trend is not statistically significant at the 5% level, with a Model F-value of 3.66 and a p-value of 0.0797, indicating a 7.97% chance that the effects observed may be due to random variation. The R^2 value (0.2340) and adjusted R^2 (0.1701) reflect weak explanatory power, while the negative predicted R^2 (-0.3119) suggests poor forecasting ability, where even a mean response would offer better predictions. A high coefficient of variation (47.65%) indicates substantial data dispersion, undermining the model's reliability. Though the adequate precision value (4.366) slightly surpasses the acceptable threshold (>4), the overall statistical indicators highlight the need for model revision or simplification to improve its validity and predictive performance (Montgomery, 2017; Myers *et al*., 2016) [17, 22]. In contrast, Figure 3.5 illustrates the moisture ratio trend during drying of control cauliflower, showing a steady decline from 1.00 to 0.11 over time. The rapid drop in the early phase corresponds to efficient evaporation of free moisture, while the slowing rate in the later phase indicates the gradual removal of bound moisture as the sample nears equilibrium. The corresponding ANOVA confirms the statistical significance of the model, with a Model F-value of 334.08 and a p-value of 0.0001, indicating only a 0.01% probability that the result is due to random error. The factor A (time) significantly influences the moisture ratio, as its p-value is below 0.05. The model demonstrates excellent reliability and predictive accuracy, supported by high R^2 (0.9653), adjusted R^2 (0.9624), and predicted R^2 (0.9462) values. A moderate yet acceptable C.V. (11.89%) and a strong adequate precision value (41.680) further validate the robustness of the model for predicting moisture ratio and optimizing the drying process under varying conditions.

3.1.2 Drying Kinetics of Blanched Samples (T2) in Tray Dryer at 60 °C

Figures 3.6 to 3.7 depict the drying behavior of blanched cauliflower, showing weight reduction from 2500 g to 250 g over 13 hours with a clear shift from constant- to falling-rate drying. Moisture content dropped from 90% (dry basis) to 22%, indicating efficient water removal due to blanching. Statistical models for all figures were highly significant (F-values: 107.39-127.99, $p < 0.0001$), with strong R^2 values (≥0.8995), good predicted accuracy, and high adequate precision (≥23.631), confirming excellent model fit and predictive reliability.

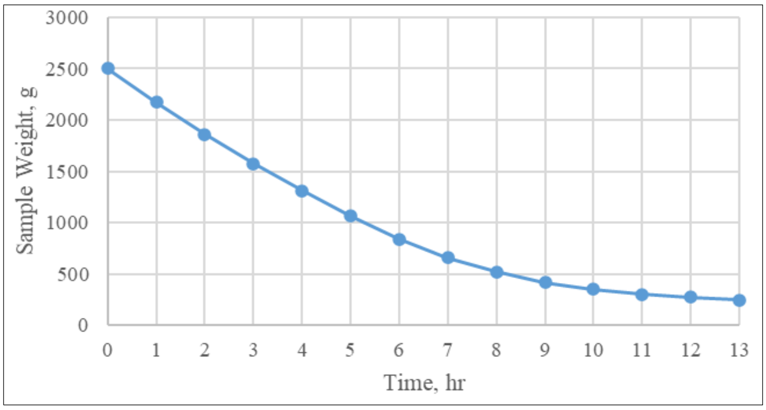

Fig 3.6: Change in Weight of Blanched Cauliflower with Drying Time at 60 °C

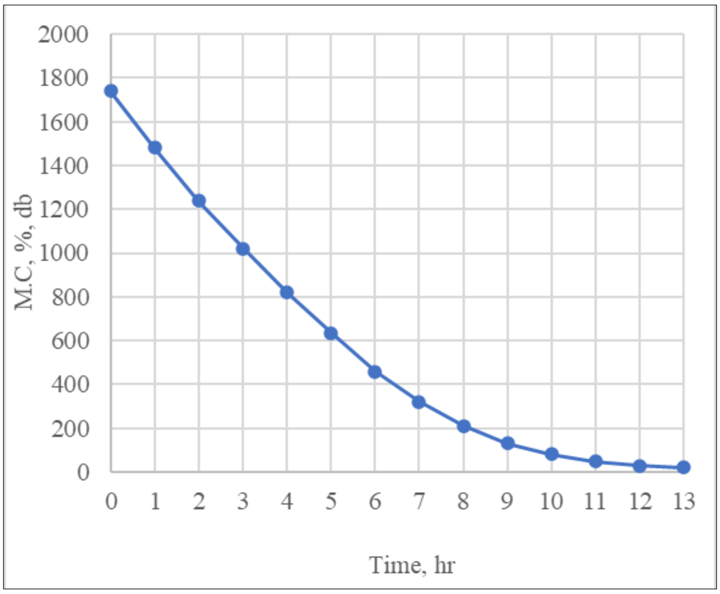

Fig 3.7: Change in Moisture Content (%, Dry Basis) of Blanched Cauliflower with Drying Time at 60 °C

Figures 3.8-4.10 show drying trends of cauliflower with rapid initial moisture loss (65 g/hr) in the first hour, slowing over time due to transition from free to bound moisture (Mujumdar, 2006; Kingsly *et al.*, 2007) [19, 13]. ANOVA confirms moderate model significance for moisture loss and drying rate ($F = 8.12$, $p < 0.05$; $R^2 \approx 0.40$, Adequate Precision = 6.500), though negative predicted R^2 indicates limited forecasting. In contrast, the moisture ratio curve (Fig. 4.10) shows exponential decline (1.00 to 0.01), with highly significant model fit ($F = 118.57$, $R^2 = 0.9081$, Adequate Precision = 24.831), validating use of thin-layer drying models (Akpinar *et al.*, 2003) [1].

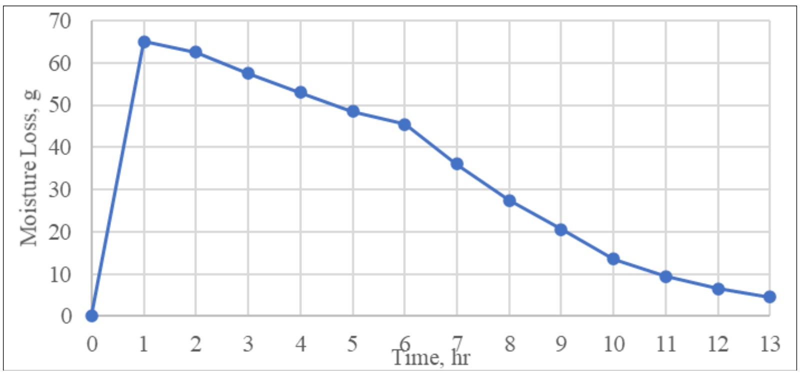

Fig. 3.8: Moisture Loss (g) of Blanched Cauliflower vs. Drying Time at 60 °C

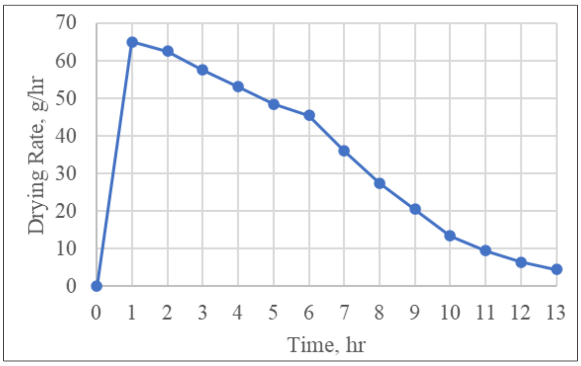

Fig. 3.9: Drying Rate of Blanched Cauliflower with Respect to Time at 60 °C

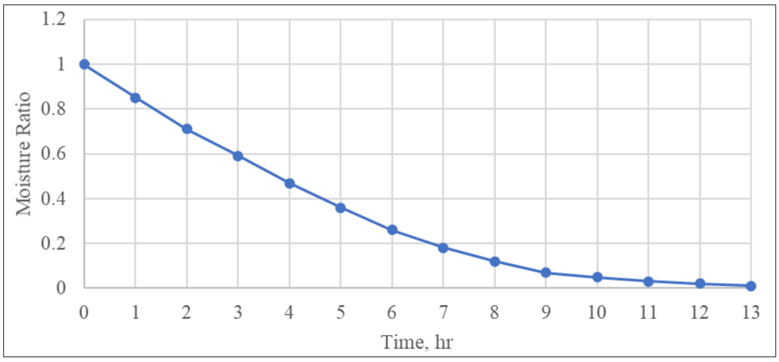

Fig. 3.10: Moisture Ratio of Blanched Cauliflower as a Function of Drying Time at 60 °C

3.1.3 Drying Kinetics of citric acid (T-3) in Tray Dryer at 60 °C

Citric acid-treated cauliflower dried at 60^{0}C over 13 h showed substantial weight loss (2800 g to 392 g; Fig. 3.11). ANOVA confirmed strong model significance (F = 182.97, R^2 = 0.9385, Adj R^2 = 0.9333, Pred R^2 = 0.9058, Adequate Precision = 30.846), validating its suitability. Moisture content (Figs. 3.12) dropped from 94.53% to 63.2% (wb), supported by Chandra *et al*. (2019) [4] and Verma *et al*. (2020). Moisture content models showed high significance (F = 112.01 and 195.85), strong fit (R^2 > 0.90), acceptable variability (C.V. 6.11%-22.82%), and strong signal strength (Adequate Precision > 24), confirming model reliability for design optimization.

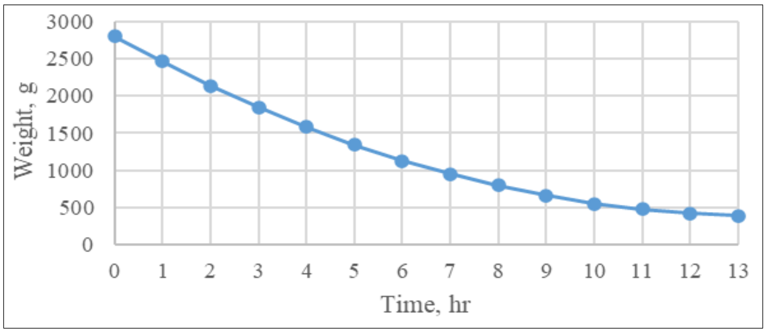

Fig. 3.11: Variation in Sample Weight of Citric Acid Cauliflower with Drying Time at 60 °C

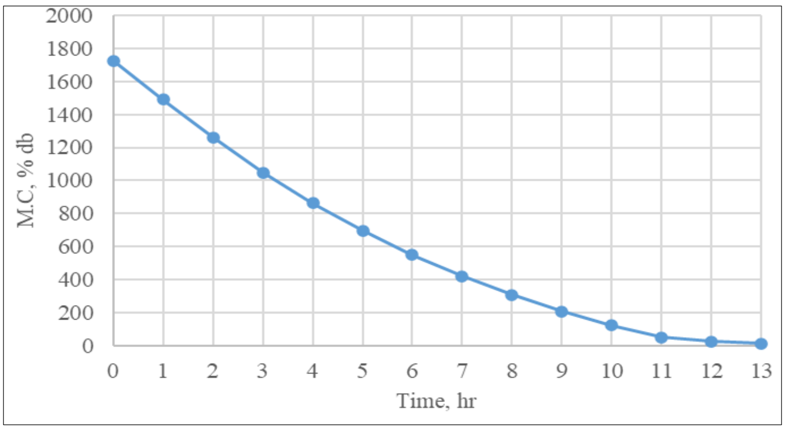

Fig 3.12: Change in Moisture Content (Dry Basis) of Citric Acid Cauliflower at 60 °C

The moisture loss curve (Fig. 3.13) mirrors the drying rate, with peak loss in the first hour (65 g), tapering to 4.5 g by the last hour reflecting classical drying behavior of blanched vegetables (Arora & Panwar, 2015; Mujumdar, 2007) [2, 20]. This confirms the efficiency of tray drying at 60 °C in reducing moisture and enhancing shelf life. The moisture ratio model yielded a significant F-value (6.65), showing time (A) impacts the response, though low R^2 (0.3566), Adj R^2 (0.3030), and negative Pred R^2 (-0.0995) indicate poor predictability. A high C.V. (53.48%) and marginally acceptable Adequate Precision (5.881) further limit its predictive utility. The drying rate (Fig. 3.14) peaked at 2.2 g/min in the first hour (constant rate period) and declined during the falling-rate period due to internal diffusion. Its model showed significance (F = 9.94), with time, A^2, and A^3 as influential terms. While R^2 = 0.7489 and Adj R^2 = 0.6736 indicate moderate fit, a negative Pred R^2 (-0.2004) and high C.V. (36.60%) reduce reliability, though Adequate Precision (7.480) supports exploratory use. The moisture ratio graph (Fig. 3.15) exhibited an exponential drop from 1.0 to 0.01, confirming effective drying. Its model was highly significant (F = 197.55), with strong predictive performance (R^2 = 0.9427, Adj R^2 = 0.9380, Pred R^2 = 0.9116), acceptable variability (C.V. = 22.75%), and excellent signal strength (Adequate Precision = 32.051), validating its utility for design space optimization.

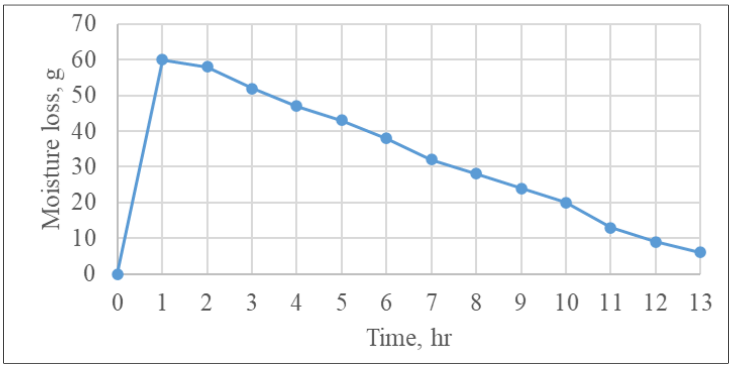

Fig. 3.13: Moisture Ratio of Citric Acid Cauliflower as a Function of Drying Time at 60 °C

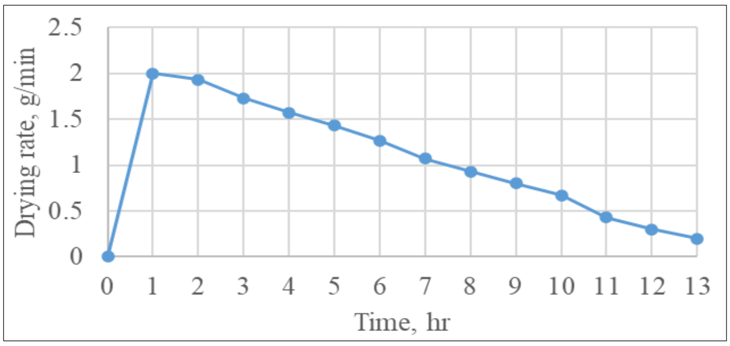

Fig. 3.14: Drying Rate of Citric Acid Cauliflower Samples during Tray Drying at 60 °C

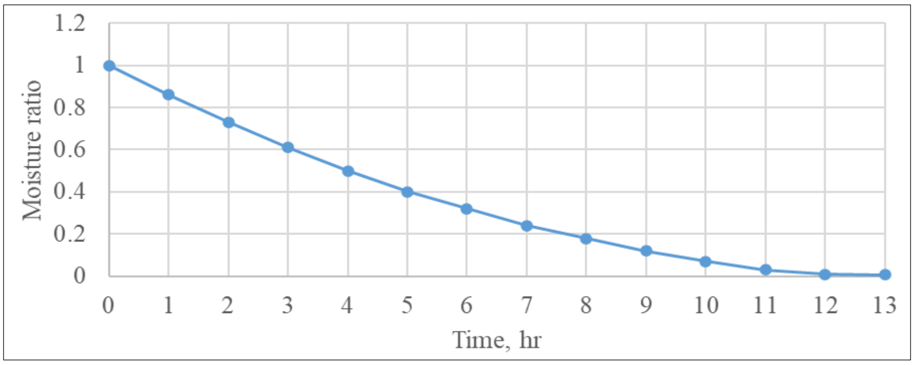

Fig. 3.15: Moisture Loss of Citric Acid Cauliflower Samples Over Drying Time at 60 °C

3.1.4 Drying Kinetics of Potassium Metabisulfite Cauliflower Samples (T4) in Tray Dryer at 60 °C

The drying behavior of KMS-treated cauliflower at 60 °C showed a steady weight reduction from 2560.0 g to 370.0 g over 13 hours due to moisture evaporation (Fig. 3.16). The model's high significance (F = 280.06, p<0.0001), with time (A) being a key influencing factor. The model exhibits strong predictability (R^2 = 0.9589, Adj R^2 = 0.9555, Pred R^2 = 0.9370), low variability (C.V. = 12.17%), and excellent precision (38.162), making it reliable for representing the drying trend. Figures 3.17 illustrate a sharp decline in moisture content of KMS-treated cauliflower during drying dropped from 94.53% to \ 50%, while M.C. (db) highlighting the sensitivity of dry basis values. The model's significance (F = 70.03, p<0.0001), with time (A) as a major factor. The model explains 85.37% of variability

($R^2 = 0.8537$), with good agreement between adjusted (0.8415) and predicted (0.7749) R^2 values. A low C.V. of 7.14% and high Adeq Precision (19.083) ensure model reliability.

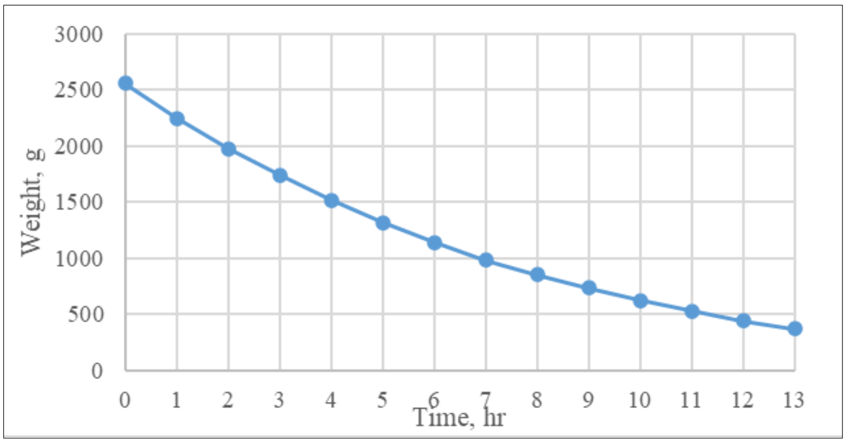

Fig. 3.16: Variation of Sample Weight of Potassium Metabisulfite Cauliflower with Drying Time

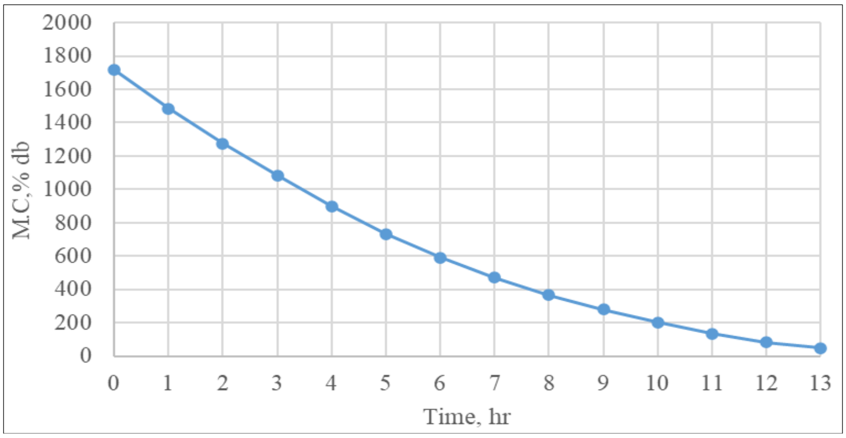

Fig 3.17: Change in Moisture Content (dry) of Potassium Metabisulfite Cauliflower with Drying

Figure 3.18 shows that moisture loss in KMS-treated cauliflower began high (~60 g) and gradually decreased, typical of drying patterns. However, the model was not statistically significant ($F = 4.27$, $p = 0.0611$), with low R^2 (0.2625), negative predicted R^2 (-0.2643), and a high C.V. (48.73%), indicating poor fit and high variability. Similarly, Figure 3.19 showed the drying rate peaked in the first hour (~2.0 g/min) and then declined, indicating a transition from surface evaporation to diffusion-driven drying, but again the model lacked statistical significance and predictive strength. Despite Adequate Precision (4.712) meeting the minimum, poor model metrics suggest unreliability. In contrast, Figure 3.20 showed an exponential decline in moisture ratio from 1.00 to ~0.01, demonstrating effective moisture removal. The model was highly significant ($F = 211.24$, $p < 0.0001$), with strong R^2 (0.9462), adjusted R^2 (0.9418), predicted R^2 (0.9182), and acceptable C.V. (19.70%). Adequate Precision (33.143) confirmed strong model precision and predictability. Collectively, these findings confirm that blanching enhances moisture diffusivity and supports more efficient drying, aligning with Zhang *et al*. (2016) [32], and Yadav *et al*. (2019) [30].

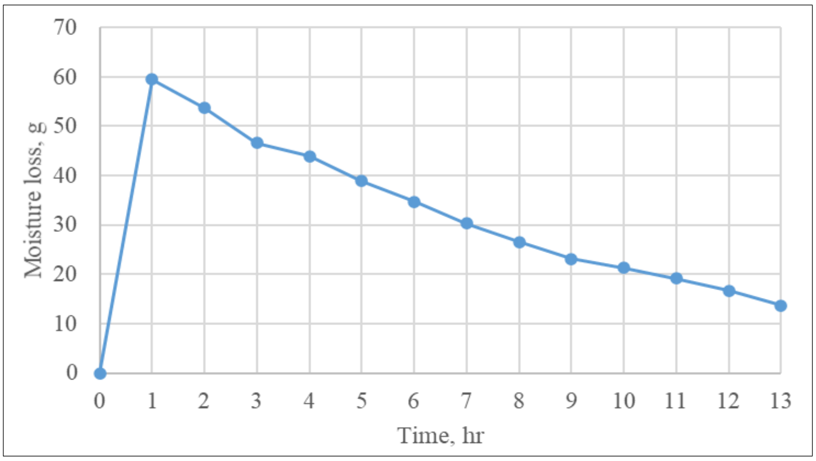

Fig 3.18: Moisture Loss of Potassium Metabisulfite Cauliflower with Drying Time

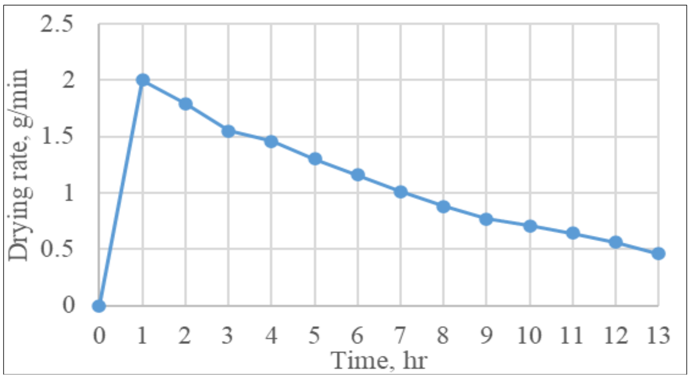

Fig 3.19: Drying Rate of Potassium Metabisulfite Cauliflower with Drying Time

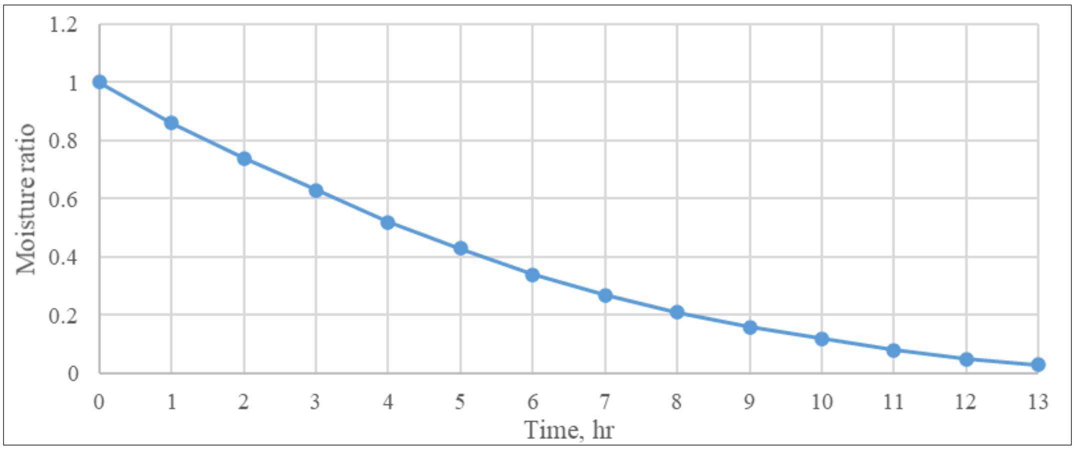

Fig. 3.20: Moisture Ratio of Potassium Metabisulfite Cauliflower with Drying Time

3.1.5 Regression Models for Drying Characteristics of Cauliflower under Different Treatments

This table 4.28 presents the reduced regression models describing the relationship between time (A) and various drying responses for control, blanched, citric acid-treated, and KMS-treated cauliflower samples. Each model quantifies the rate of change of sample weight, moisture content, moisture loss, drying rate, and moisture ratio with respect to time, enabling prediction of drying behavior under different treatments.

3.4 Regression Models for Drying Characteristics of Cauliflower under Different Treatments

Response	Reduce model in terms of the actual factor			
	Control	Blanched Cauliflower	Citric Acid Cauliflower	KMS
Sample Weight	Y = 1043.14 -765.94×A	Y =1008.04−1128.82×A	Y = 1254.40 -1203.36× A	Y = 1217.09 -1068.05× A
Moisture Content (Wet Basis)	Y = 83.63 -14.88×A	Y = 67.71−40.90×A	Y = 79.22-22.06×A	Y = 80.82 -20.82×A
Moisture Content (dry Basis)	Y = 808.29 -728.79×A	Y= 588.21 -863.67×A	Y =626.49-862.03 × A	Y = 669.16 -827.82×A
Moisture Loss	Y = 112.80 -44.34×A	Y =160.71−114.64×A	Y = 172.00 -102.24× A	Y = 156.43 -67.88 × A
Drying Rate	Y = 1.88 -0.74×A	Y = 160.71 -114.64× A	Y=172.00 -102.24× A	Y = 156.43 -67.88×A
Moisture Ratio	Y= +0.46 -0.43×A	Y = 0.34 -0.50× A	Y = 0.36 -0.50× A	Y = 0.39 -0.48× A

Note: Y is the response variable, and A (time) is the independent parameter.

4 Conclusion

The present study effectively demonstrated that the optimization of osmotic dehydration and appropriate pre-treatments can significantly enhance the drying efficiency and storage quality of cauliflower. Among the various pre-treatments examined control, blanching, citric acid, and potassium metabisulphite (KMS) blanching and citric acid treatments were found to considerably improve drying kinetics, reduce drying time, and retain better nutritional and sensory attributes. The drying behavior followed the expected two-phase pattern: an initial constant-rate period followed by a falling-rate period, with rapid moisture loss in the early stages and gradual decline as drying progressed. Statistical modeling and regression analyses validated the predictive capability of drying parameters across different treatments, with high R^2, low C.V., and strong adequate precision values in most cases. The regression models established for sample weight, moisture content, moisture loss, drying rate, and moisture ratio across different treatments provide useful tools for predicting drying behavior and optimizing processing conditions. Post-drying storage studies revealed that packaging plays a vital role in preserving product quality. Among the tested materials, aluminum foil demonstrated superior barrier properties, maintaining lower moisture uptake and better retention of ascorbic acid and color compared to HDPE. These findings underscore the importance of integrating effective pre-treatment, optimized osmotic conditions, and suitable packaging for achieving longer shelf life and improved product stability. In conclusion, the integration of blanching or citric acid pre-treatment with 2-3% brine osmotic dehydration and tray drying at 60 °C, followed by storage in aluminum foil packaging, can be recommended as an effective preservation strategy for cauliflower. This approach not only minimizes post-harvest losses but also adds value by enhancing storage stability and marketability, particularly benefiting small-scale farmers and processors in regions lacking advanced cold chain infrastructure. Further studies on scaling up, energy efficiency, and consumer acceptability would support commercialization of this technique in the processed vegetable sector.

References

1. Akpinar EK, Bicer Y, Yildiz C. Thin layer drying of red pepper. J Food Eng. 2003;59(1):99-104.
2. Arora S, Panwar N. Effect of drying methods on quality characteristics of cauliflower powder. Int J Food Sci Nutr. 2015;4(2):33-38.
3. Azeem M, Nasir M, Anjum MA, Randhawa MA, Ali S. Nutritional and health-promoting properties of cruciferous vegetables: A review. J Food Sci Technol. 2023;60(3):559-569.
4. Chandra A, Verma AK, Srivastava R. Impact of pretreatments on the drying characteristics of vegetables: A review. Food Rev Int. 2019;35(6):510-31.
5. Chandra S, Das H. Statistical optimization of process parameters for osmotic dehydration of pomegranate seeds. J Food Eng. 2008;86(3):422-432.
6. Environmental Protection Agency. Sustainable packaging: Innovations in active and intelligent systems [Internet]. 2023 [cited 2025 Sep 8]. Available from: www.epa.gov
7. Food and Agriculture Organization of the United Nations. FAOSTAT database [Internet]. 2023 [cited 2025 Sep 8]. Available from: www.fao.org/faostat
8. Fellows PJ. Food processing technology: Principles and practice. 2nd ed. Cambridge: Woodhead Publishing; 2000.
9. Gupta S, Sharma P, Saini R. Effect of drying methods on the quality of dehydrated cauliflower. J Food Sci Technol. 2012;49(1):109-113.
10. Gupta A, Yadav R, Singh P. Post-harvest losses and management strategies in vegetable crops: A case of cauliflower. J Hortic Res. 2022;30(2):45-54.
11. Hemaprabha G, Sankaranarayanan VM, Sundaram PA. Effect of blanching and chemical treatments on quality characteristics of dehydrated cauliflower. South Indian Hortic. 2003;51(5-6):332-336.
12. Kadam DM, Wilson RA, Kaur P. Advances in osmotic dehydration of fruits and vegetables. Drying Technol. 2023;41(2):245-262.
13. Kingsly ARP, Goyal RK, Manikantan MR, Ilyas SM. Effects of pretreatments and drying air temperature on drying behavior of peach slice. Int J Food Sci Technol. 2007;42(1):65-69.
14. Li J, Zhang Y, Wang Y. Glucosinolates and health-promoting effects of cauliflower. Crit Rev Food Sci Nutr. 2022;62(4):954-971.
15. Mahapatra AK, Sutar PP, Pal US. Osmotic dehydration in food processing: A review. J Food Process Preserv. 2022;46(6):e16542.
16. Mohanta S. Effect of drying and packaging materials on storage quality of dehydrated cauliflower. Indian Food Packer. 2008;62(4):58-63.
17. Montgomery DC. Design and analysis of experiments. 9th ed. Hoboken: Wiley; 2017.
18. Mudgal VD, Pandey A. Effect of blanching and additives on the quality of dehydrated vegetables. Indian J Agric Sci. 2008;78(2):138-142.
19. Mujumdar AS. Principles, classification, and selection of dryers. In: Mujumdar AS, editor. Handbook of industrial drying. 3rd ed. Boca Raton: CRC Press; 2006. p. 3-32.
20. Mujumdar AS. Fundamentals of drying and dehydration of foods. Enfield: Science Publishers; 2007.
21. Mujumdar AS, Law CL. Drying of agricultural and food products: Recent advances and future trends. Food Bioprod Process. 2022;130:1-19.
22. Myers RH, Montgomery DC, Anderson-Cook CM. Response surface methodology: Process and product optimization using designed experiments. 4th ed. Hoboken: Wiley; 2016.
23. Ratti C. Advances in food dehydration. Boca Raton: CRC Press; 2005.
24. Saini R, Kaur N, Aggarwal P. Emerging technologies in food packaging: Active, intelligent, and biodegradable materials. Trends Food Sci Technol. 2023;136:230-245.
25. Shrivastava RP, Sulebele GA. Effect of blanching on the quality of dehydrated cauliflower. Indian Food Packer. 1995;49(3):23-27.
26. Singh R, Kumar R, Awasthi S. Role of cruciferous vegetables in human health. Int J Nutr Funct Foods. 2023;9(1):1-12.
27. Tijskens LMM, Evelo RG, O'Brien M. Modelling the effect of temperature on the rate of enzyme inactivation. J Food Eng. 2002;54(3):205-213.
28. Verma AK, Srivastava R, Chandra A. Impact of pretreatment on the drying behavior of vegetables. Indian J Food Process Technol. 2020;37(2):120-129.
29. Verma A, Singh D, Sinha S. Optimization of osmotic dehydration parameters in cauliflower. J Food Eng Technol. 2024;12(1):89-97.
30. Yadav SK, Singh G, Meena RS. Effect of drying on the quality of cauliflower and its utilization in food products. Indian J Agric Sci. 2019;89(6):1021-1025.
31. Yuan L, Chen Z, Wu H. Innovative blanching techniques for improved energy efficiency and nutrient retention. Food Eng Rev. 2022;14(4):509-528.
32. Zhang M, Tang J, Mujumdar AS, Wang S. Trends in microwave-related drying of fruits and vegetables. Trends Food Sci Technol. 2016;17(10):524-534.