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RESEARCH ARTICLE

EVALUATION AND THERMAL-ANALYSIS OF A SOLAR-ASSISTED DRYING-SYSTEM: DRYING CAPACITY AND EFFICIENCIES

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ABSTRACT

In this part of the study on thermal analysis of solar-assisted drying-system, the drying capacity and efficiencies of the system are discussed. The evaporative capacity and mass shrinkage ratio started at higher values and then decreased continuously toward the end of the drying process. The pick-up efficiency is increased with the increment in the drying-air velocity from 1.5m/s to 3m/s. In contrast, an inverse relationship is found with the drying-air temperature. The values of specific heat consumption are decreased as the drying-air temperature is increased.

KEYWORDS

Solar-drying; evaporative-capacity; pickup-eff.; shrinkage-ratio; SHC, SMER; Roselle

1. INTRODUCTION

For over hundred years, fossil fuels have been the primary source of energy for industries and societal needs (Aydin et al., 2021; Hassan et al., 2023). The depletion of fossil resources and their detrimental impact on the environment have prompted a transition toward sustainable energy-sources. Renewable energies, like solar radiation, play a crucial role in restoring the natural balance and meeting the demands of our growing population (Sarbu and Sebarchievici, 2018; Twidell and Weir, 2015). The plentiful availability and affordability of the solar energy (as a renewable energy source) are the significant strategic-benefits, making it an excellent energy-alternative for both developed and developing nations (Kachare and Shinde, 2019).

Many of the third-world countries produce large quantities of vegetables and fruits. Unfortunately, more than 30% may be lost because of the spoilage (Headley, 1997). The annual global food-waste is around 1300million tons, exacerbates global warming (Hassan et al., 2023; Kumar et al., 2014; Pham et al., 2020). The bulk of this waste occurring in developed nations during consumption and in developing nations at the initial stages of the food chain, particularly during post-harvest and processing (Amini et al., 2020; Daliran et al., 2023).

Unsuitable preservation and storage methods cause losses of food, which are according to a study, ranged between 10-30% for cereals, and 50-70% for fruits (Yaldiz and Ertekyn, 2001). It is essential, therefore, to utilize dependable storage systems and combine post-harvest techniques, such as drying, to transform perishable products into more stable forms. These stabilized products can then be stored in a controlled environment for an extended duration (Chua and Chou, 2003).

Drying is a fundamental and one of the oldest preservation techniques for food and agricultural produce (Kant et al., 2016). Its primary goals are to lower moisture levels to inhibit microbial growth and reduce detrimental chemical and physical reactions throughout the storage-transport processes, as well as to safeguard the produce by preventing enzymatic changes (Daliran et al., 2023; Tripathy and Kumar, 2009; Araujo et al., 2020; Barbosa et al., 2023). Additionally, it reduces the volume and weight of goods for transportation and storage (Barbosa et al., 2023).

Drying, is complicated-process, which entails simultaneous heat-mass transfer, influenced by the product's external-internal resistances. The internal moisture transfer mechanism during the drying of agricultural products primarily involves capillary action during the constant drying rate period and diffusion during the falling drying rate period (Barbosa et al., 2023; Yu et al., 2020). Drying as a mean of food preservation is very important for food safety and security. It preserves the nutritional value and quality of food (Hassan et al., 2023; Khan et al., 2018). However, drying and dehydration of fresh fruits and vegetables, is one of the most energy-intensive processes in the food industry and account for about 15% of total industrial energy use (Khan et al., 2020; Kumar et al., 2018). Numerous drying technologies still rely on fossil fuel-based power sources, contributing to environmental pollution (Hassan et al., 2023).

Apart from the rise in energy costs, legislation on pollution, sustainable and eco-friendly technologies have created a greater demand for energy efficient drying processes in the food industry. The food industry can reduce costs by minimizing energy waste. A mere 1% improvement in energy-efficiency could lead to a substantial 10% profit increase (Beedie, 1995). High-temperature drying primarily results in issues such as shrinkage, excessive-burning, case hardening (Kadam and Samuel, 2006). Solar drying is a non-polluting process, uses the abundant-renewable and energy source, which cannot be monopolized (Imre, 1986). Solar drying can serve as a superior alternative to traditional sun drying and overcome the drawbacks of traditional open-air and industrial drying methods, and conserve substantial amounts of fossil fuels (Dina et al., 2015; Bal et al., 2010). Solar-drying stands-out as sustainable option, harnessing solar energy to dry agricultural produce (Arthur and Karim, 2016). Indirect solar drying is more efficient than direct methods, offering higher temperatures, shorter drying times, and better product quality (Hassan et al., 2023; EL-Mesery et al., 2022).

Solar dryers offer benefits that surpass mere environmental considerations. They can lower drying-costs as 80% as possible, enhance the quality of the end product, lessen gas-emissions (greenhouse-gas), and they are ready/easy to configure and operate (Barbosa et al., 2023; Jain et al., 2023). Researchers aim to perfect solar-drying-systems, to produce high-quality products using minimal time and energy (Khouya, 2020).

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Solar-drying processes and drying systems can be described and evaluated, using drying-material and system terms. The most important structural variation appeared on the crop (due to the weight loss) is the mass shrinkage ratio (Midilli, 2001).

For the solar-assisted drying system, the evaporative capacity pickup efficiency, system drying efficiency, specific moisture extraction rate (SMER) or the thermal efficiency, specific heat consumption coefficient of performance or the energy efficiency, overall thermal efficiency of the solar drying system and solar fraction are the most used terms in the literature. Incorporating a desiccant with solar-systems resulted in a substantial-decrease in energy-consumption for each kg of removed-moisture (Jannot and Coulibaly, 1998; Mumba, 1996; Shanmugam and Natarajan, 2006; Brenndorfer et al., 1985; Hassan et al., 2023; Brundrett, 1987; Hawlader and Jahangeer, 2006; Pakowski and Mujumdar, 1995; Nedo, 1984;Sopian et al., 2023; Pakowski and Mujumdar, 1995; Stehli and Escher, 1990; Duffie et al., 2020; Chua and Chou, 2003). The objectives of this part, of the work on thermal-analysis of solar-assisted drying-system, are to examine the drying capacity and efficiencies, where thin-layer drying experiments with Roselle (*Hibiscus sabdariffa* L.) are conducted.

2. Mathematical Modeling

Energy efficiency is generally assessed by comparing the energy required for a process to the energy provided. Not all energy transferred during drying is used for moisture reduction; significant energy loss occurs with the exhaust air (Barbosa et al., 2023).

Drying process and system efficiencies:

Evaporative capacity (E): is the maximum rate at which water can be extracted by the drying-air from the product (Jannot and Coulibaly, 1998). It can be expressed using air-humidity, and weight or moisture content differences:

$$E = \dot{m}_{da}(X_2 - X_1) = \dot{m}_{da}(W_1 - W_2) \quad (1)$$

The term (W_1-W_2) is the weight or moisture content differences (Sopian et al. 2003).

Mass shrinkage ratio (SR) is given by (Midilli, 2001; Shanmugam and Natarajan, 2006):

$$SR = \frac{W_t}{W_0} \quad (2)$$

Pickup efficiency (η_p): it determines the efficiency of moisture removal by the drying-air from the product (Mumba, 1996; Shanmugam and Natarajan, 2006). This represents the ratio of moisture absorbed by the air in the drying-chamber to its theoretical-moisture absorption-capacity (Brenndorfer et al., 1985):

$$\eta_p = \frac{W}{V\rho\, t\,(h_{as} - h_i)} = \frac{W_0 - W_t}{m_a\, A\, t\,(h_{as} - h_i)} = \frac{(h_0 - h_i)}{(h_{as} - h_i)} \quad (3)$$

System drying efficiency (η_d): It represents the ratio of the needed energy to evaporate the moisture from the drying material, to the energy-provided to the drying system. It can be expressed as (Brenndorfer et al., 1985):

$$\eta_d = \frac{W\,.\,L}{I_c\, A_c} \quad (4)$$

Specific-moisture extraction-rate ($SMER$) or the thermal efficiency (η_{th}), is the performance index used to describe any solar drying system (Shi et al., 2008; Qiu et al., 2016; Wang et al., 2019; Pakowski and Mujumdar, 1995). It is used to express the effectiveness of the drying, and is defined as the ratio of the moisture removed (kg) to the energy input (kWh) (Hassan et al., 2023; Hawlader and Jahangeer, 2006; Bantle et al., 2014):

$$SMER = \frac{Moisture\ removed\ (kg)}{Total\ energy\ input\ to\ the\ dryer\ (kWh)} \quad (5)$$

Specific heat consumption ($kJkg_w^{-1}$): is the ratio of the amount of heat supplied to the mass of water evaporated (Pakowski and Mujumdar, 1995):

$$SHC = \frac{Amount\ of\ heat\ supplied}{Mass\ of\ water\ evaporated} \quad (6)$$

Coefficient of performance (COP_{th}) or the energy efficiency (η_e), is the ratio of the energy used for moisture-evaporation in the dryer to the total supplied-energy to it (Hassan et al., 2023; Nedo, 1984; Sopian et al., 2023; Pakowski and Mujumdar, 1995):

$$COP_{th} = \eta_e = \frac{Q_{evaporation}}{Q_{total}} \quad (7)$$

Overall thermal efficiency (η_{th}): is the ratio of the heat amount to be supplied to the dryer (the heat used to evaporate the moisture) and the solar radiation incident on the plane of the solar collector. It can be expressed as (Sopian et al., 2023; Stehli and Escher, 1990):

$$\eta_{th} = \frac{Q_w}{G_T\, A_{ct}} = \frac{Q_{in}}{G_T A_{ct}} \cdot \frac{Q_w}{Q_{in}} = \eta_c\, COP_{th} \quad (8)$$

3. Results and Discussions

For this work, thin-layer solar drying experiments with Roselle are conducted in solar assisted dehumidification drying system. Five temperatures (35,45,55,60, and 65°C) and two air-velocities (1.5m/s & 3m/s) are tested. Initial moisture-contents (IMC), and equilibrium moisture-contents (EMC) of the Roselle samples are given in Table 1. The moisture-content is varied from initial values of 7.62-10.8 ($g_w.g_{dm}^{-1}$) to final values of 0.06-0.42 ($g_w.g_{dm}^{-1}$).

The initial weights (IW) and the amounts of water removed are presented in Figure1. The equilibrium moisture content is the dynamic EMC, calculated after the weight of Roselle is not varied significantly (< 0.01g) with the increment of the drying time (Basunia and Abe, 1999; Falade and Abbo, 2007; Hossain and Bala, 2002).

Table 1: IMC and EMC

T	Velocity	IMC		EMC	
(°C)	(m/s)	db	wb(%)	db	wb(%)
35	1.5	10.44	91.26	0.42	29.36
	3.0	10.16	91.04	0.28	22.07
45	1.5	10.29	91.14	0.26	20.53
	3.0	09.81	90.75	0.20	16.80
55	1.5	09.95	90.87	0.13	11.27
	3.0	07.62	88.40	0.11	09.76
65	1.5	10.80	91.52	0.06	05.38
	3.0	09.94	90.86	0.07	06.29

Where, db = dry base & wb = wet base

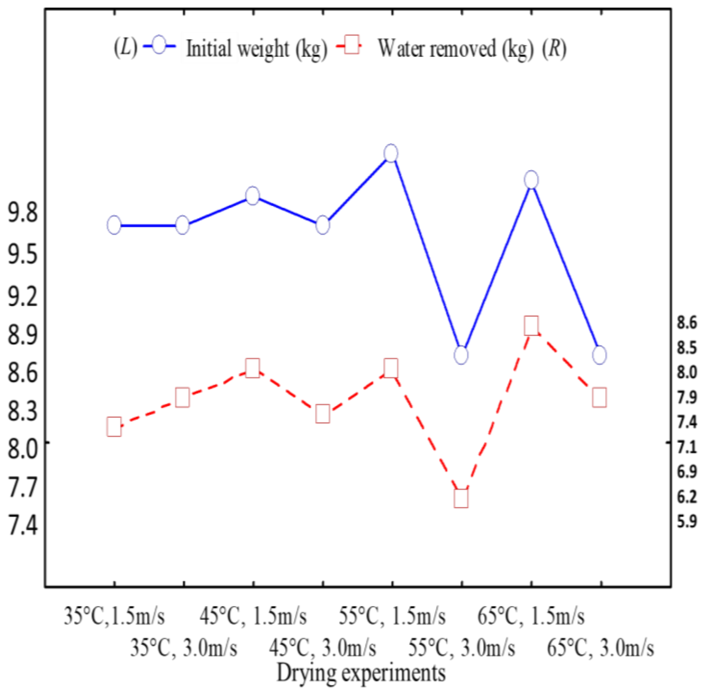

Figure 1: Initial weight and water removed

Table 2 presents the variation of the moisture ratio (MR) with drying time during the drying processes of Roselle at different drying-air conditions. Drying processes are given as percentages and the drying-time (min).

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Table 2: Moisture ratio (*MR*) and drying time (*t*)

Drying Process (%)	MR (-)	Time (*min*)							
		35°C		45°C		55°C		65°C	
		1.5m/s	3m/s	1.5m/s	3m/s	1.5m/s	3m/s	1.5m/s	3m/s
0	1.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0
10	0.90	245	110	150	110	115	95	95	95
50	0.50	1800	1110	1130	850	770	735	535	540
80	0.20	4155	2790	2710	2110	1720	1695	1150	1210
90	0.10	5580	3710	3535	2995	2250	2220	1545	1615
95	0.05	6545	4545	4345	3560	2705	2715	1835	1920
98	0.02	7480	5305	4890	4255	3095	3190	2125	2270
99	0.01	7955	5740	5190	4420	3255	3465	2295	2500

The variation of the weight losses from the trays in the drying-chamber are presented in Table 3. The Table showed the percentages of the weight losses in drying at different drying conditions. The order the arrangement of the trays in the drying-room are shown in Figure 2. The average values of the eight trays plus the drying sample (for single run) are given in the last row. The samples are hung to a digital balance and the weight is recorded to the PC. The Roselle in the upper trays showed low drying percentages compared to the other, which necessitate the usage of mechanism to direct the air from top-to-bottom or shifting the tray locations, to have a uniform drying in the entire trays.

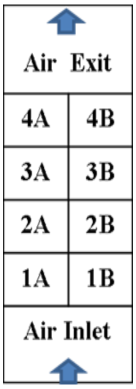
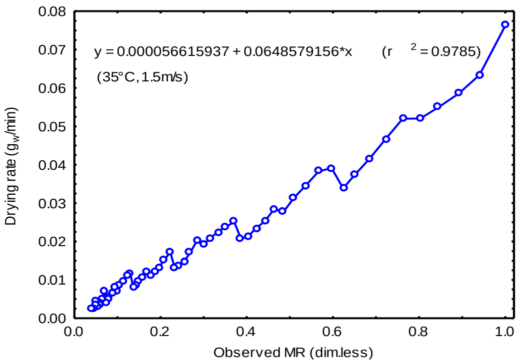


Figure 2: Order of drying trays

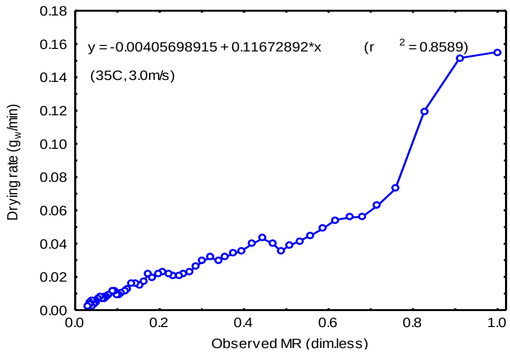
Table 3: Weight losses of Roselle (solar-experiments) (%)

Drying Trays	35°C		45°C		55°C		65°C	
	1.5m/	3m/s	1.5m/	3m/s	1.5m/	3m/s	1.5m/	3m/s
1A	87.82	88.38	89.33	86.87	87.33	87.73	90.91	89.93
1B	87.16	88.50	89.56	87.94	87.28	88.37	90.59	90.02
2A	87.08	88.13	89.08	87.71	86.95	88.49	90.67	89.99
2B	85.94	88.16	89.12	87.64	86.30	88.30	90.33	89.84
3A	86.32	86.95	88.74	90.54	89.89	88.19	90.74	89.19
3B	85.15	85.63	87.38	85.09	80.62	85.70	89.15	88.20
4A	82.51	85.32	85.33	83.86	81.80	87.12	86.73	85.83
4B	84.35	84.56	86.57	82.46	77.77	88.15	86.91	85.97
Samples	87.62	88.50	88.85	88.88	89.71	87.15	91.04	90.25
Aver.	86.00	87.13	88.22	86.78	85.29	87.69	89.67	88.80

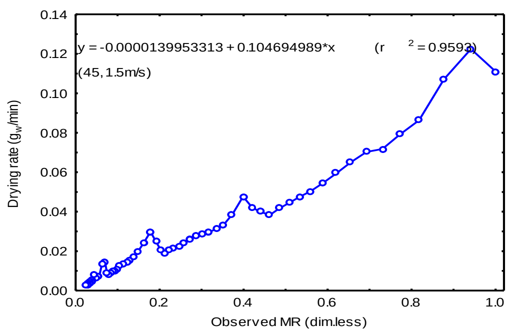
The drying curves and drying times are affected by drying-air temperature and velocity, and properties of the drying material. The open drying potential is low so that the factors limiting drying-rate is the ability of the air to carry moisture away from the crop rather than the ability of the crop to lose water to the air (Bruce et al., 2005; Kadam and Samuel, 2006). The drying-rates of Roselle as a function of the dimensionless moisture ratio (*MR*) are presented in Figure 3.



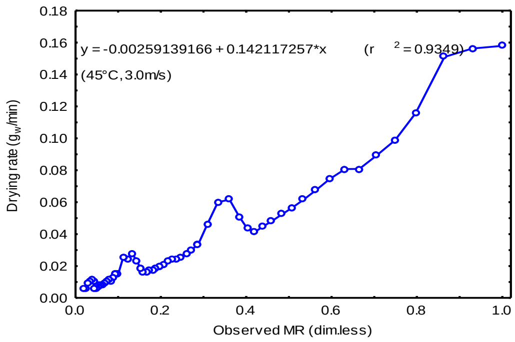
a: 35°C, 1.5m/s



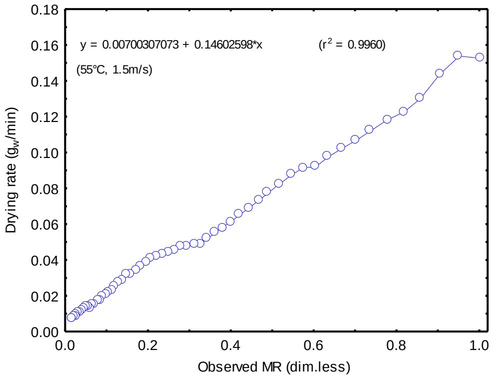
b: 35°C, 3m/s



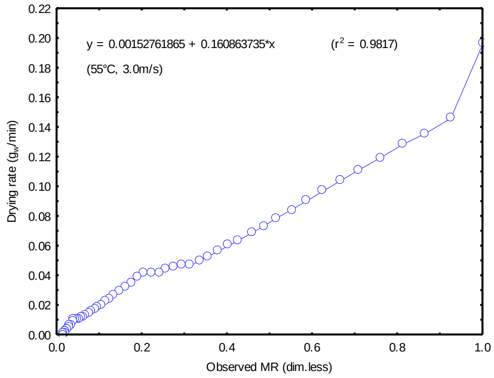
c: 45°C, 1.5m/s



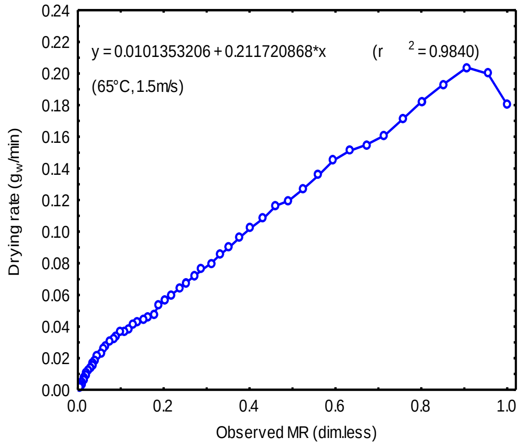
d: 45°C, 3m/s



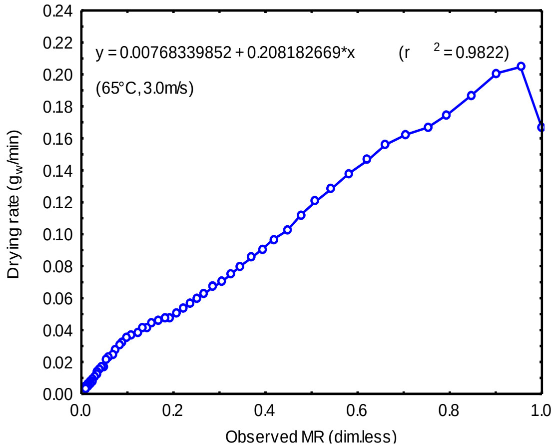
e: 55°C, 1.5m/s



f: 55°C, 3m/s



g: 65°C, 1.5m/s



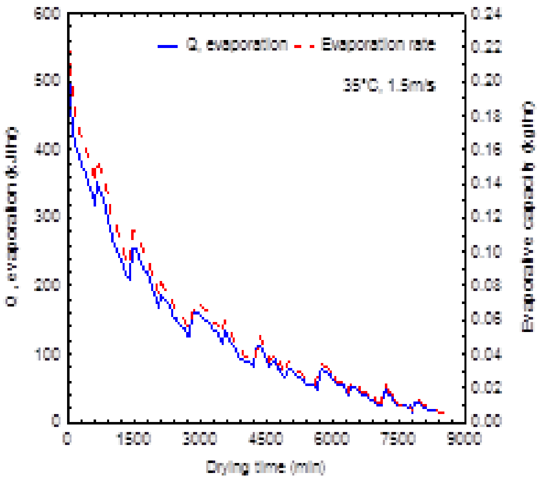
h: 65°C, 3m/s

Figure 3: Drying rate vs. observed MR

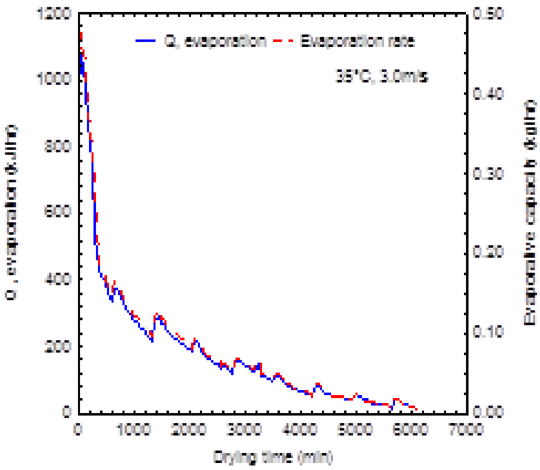
In drying the food material under low temperature and airflow, the water evaporation at the surface slowly and after long time microorganism's growth and insect's infestation will damage the dried products (Sopian et al., 2023). This is observed in drying at 35°C, 1.5m/s as the material is not reached the save-storage moisture-content (about 16%wb) after more than four days of continuous drying. Generally, at the initial stage of drying-process, the drying-rate is high and then it is slow down as the Roselle's moisture-content decreases until the finish of drying. Moreover, there is (wavy) behavior of the drying curves at low temperatures (35 and 45°C), as in Figure 3a-3d. This might be attributed to the presence of a wax layer on the Roselle's calyces and the regeneration of the silica gel columns (every 12hrs); where air properties are greatly changed. The effect is decreased as drying-temperature is increased to 55°C and 65°C, as in Figure 3e-3h.

Conversely, in drying at high temperatures and high air velocity rates, the drying rate becomes faster initially; so, the outer surface becomes dry, compact, and hard, while the inner post is still wet. The impermeable outer surface causes the water in inner part to be trapped, and drying-rate slowed down. Competition and hardening phenomenon at the outer surface of a material occurred during such drying (Yu et al., 2020). When the outer-surface of the material becomes hard, and the drying-process is continued, water from the inner part will be evaporated gradually and finally cracks will be formed at outer-surface of the material/product. Moreover, the wax layer also hinders the movement of water to the outer surface.

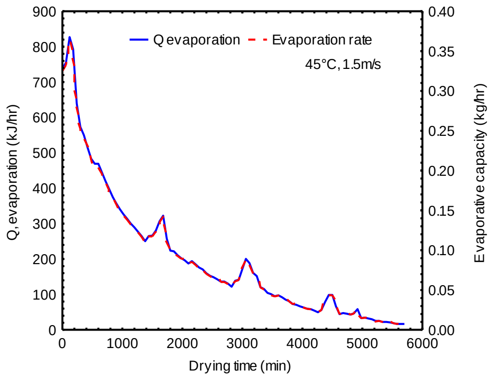
Drying-rate is expressed as evaporative-capacity. Figure 4 presented the evaporative-capacity and the evaporation energy ($Q_{evaporation}$) against drying-time. The evaporative-capacity is reliant on the moistness of materials (Sopian et al., 2023). This is clear from Figures 4a to 4h, where it is started at higher values and then decreased continuously, to end of the process, where Roselle's moisture-contents become hardly-available.



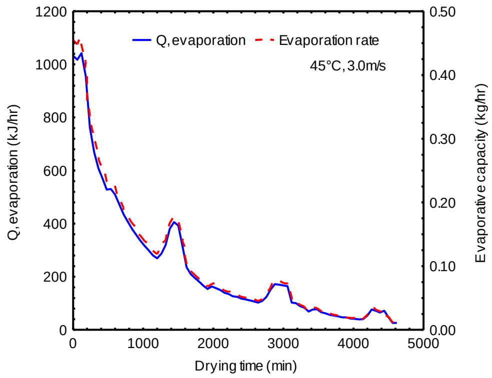
a: 35°C, 1.5m/s



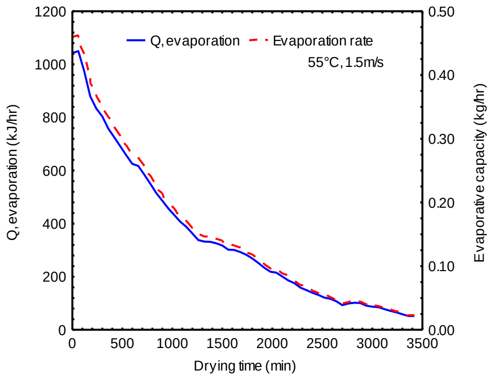
b: 35°C, 3m/s



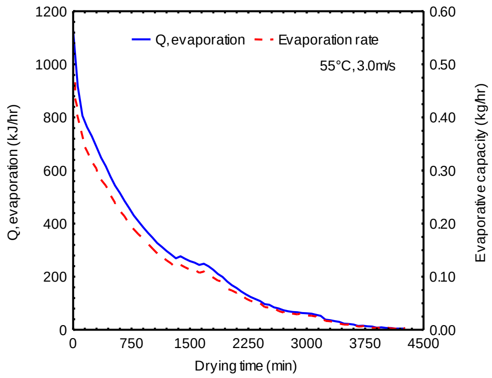
c: 45°C, 1.5m/s



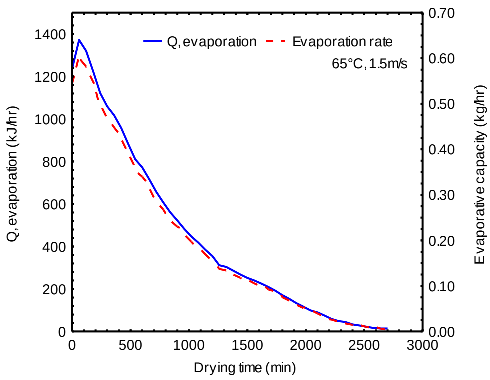
d: 45°C, 3m/s



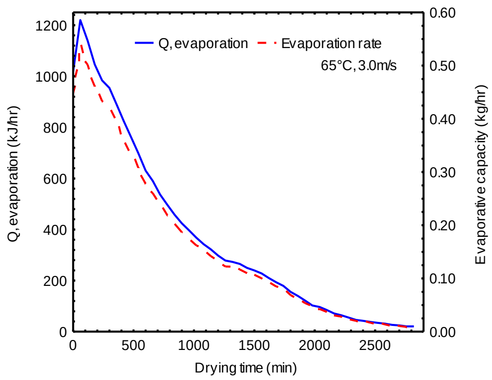
e: 55°C, 1.5m/s



f: 55°C, 3m/s



g: 65°C, 1.5m/s



h: 65°C, 3m/s

Figure 4: Evaporative capacity and evaporation energy vs. drying time

Table 4 presents the mass shrinkage ratios (*SR*) of Roselle, for each single tray, resulted from different solar drying experiments. The average values for whole trays (in single experiment) are given in the last row. The values are ranged between 0.105-0.153 for the whole trays in each single run. The mass shrinkage ratios as a function of temperature and trays' locations in the drying chamber are shown in Figure 5a and 5b, respectively.

Table 4: Mass shrinkage ratio

Order of trays	35°C		45°C		55°C		65°C	
	1.5m/s	3m/s	1.5m/s	3m/s	1.5m/s	3m/s	1.5m/s	3m/s
1A	0.122	0.116	0.107	0.131	0.127	0.123	0.091	0.101
1B	0.128	0.115	0.104	0.121	0.127	0.116	0.094	0.100
2A	0.129	0.119	0.109	0.123	0.131	0.115	0.093	0.100
2B	0.141	0.118	0.109	0.124	0.137	0.117	0.097	0.102
3A	0.137	0.130	0.113	0.095	0.101	0.118	0.093	0.108
3B	0.148	0.144	0.126	0.149	0.194	0.143	0.109	0.118
4A	0.175	0.147	0.147	0.161	0.182	0.129	0.133	0.142
4B	0.156	0.154	0.134	0.175	0.222	0.118	0.131	0.140
Aver.	0.142	0.130	0.119	0.135	0.153	0.122	0.105	0.114

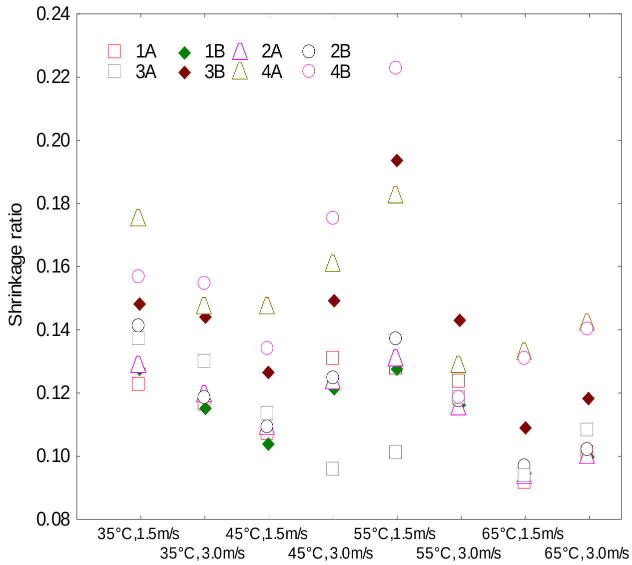


Figure 5a: SR vs. temperatures

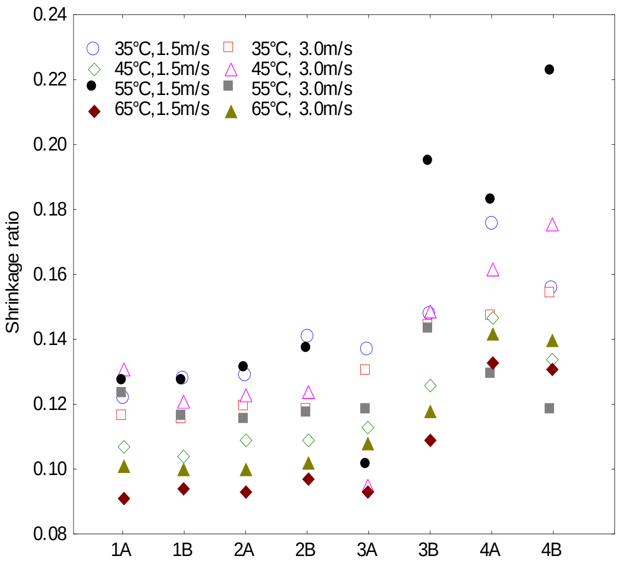


Figure 5b: SR vs. trays location

The average values of the pickup efficiency are varied between 22.413 and 9.465% for drying at (35°C, 3m/s) and (65°C, 3m/s), respectively (Figure 6). In early-phase, drying is easy, comparatively, and hence, high pickup-efficiency values are obtained, while in later-period a reduction in pickup-efficiency was observed due to the decrease in the moisture content of Roselle (Shanmugam and Natarajan, 2006). The pickup efficiency can vary widely, depending principally on the ease with which the moisture can evaporates from a commodity being dried (Brenndorfer et al., 1985).

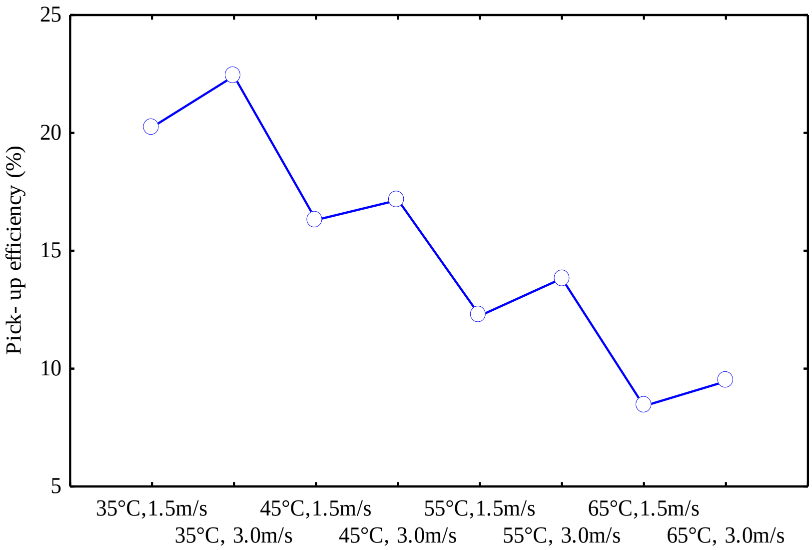
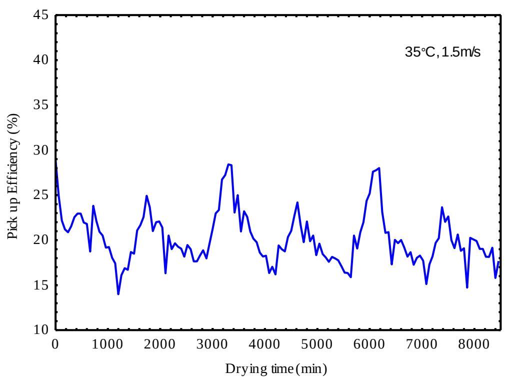
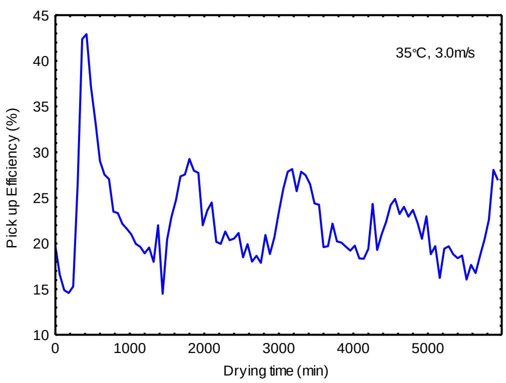


Figure 6: Average pickup efficiency (%)

Figure 7 presented the pick-up efficiency versus drying time for drying with diverse-conditions. It is noticeable that the pick-up efficiency increased as the air velocity is increased from 1.5m/s to 3m/s. Conversely, an inverse relationship is found with drying temperature. This due to the fact that, the theoretical-capacity of air to carry water at higher-temperatures (55-65°C), is greater than that of low temperatures (35-45°C).



a: 35°C, 1.5m/s



b: 35°C, 3m/s

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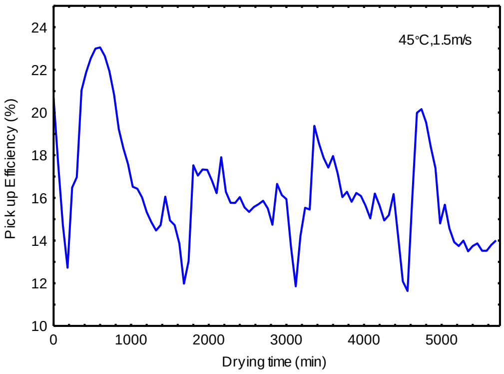
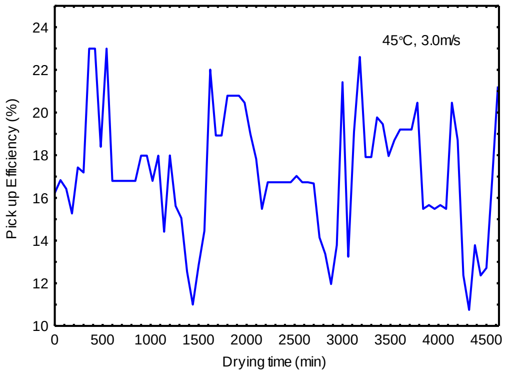
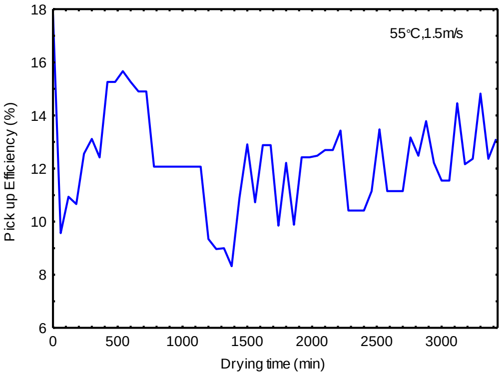


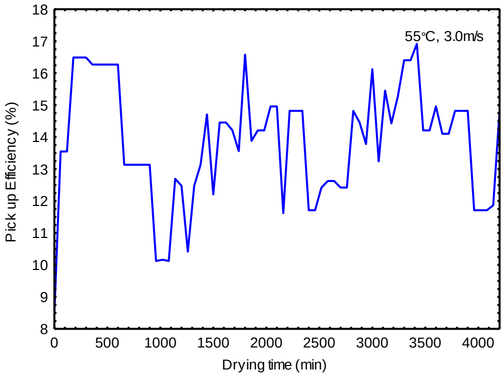
c: 45°C, 1.5m/s



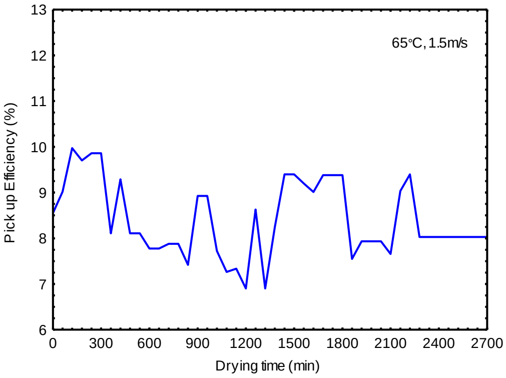
d: 45°C, 3m/s



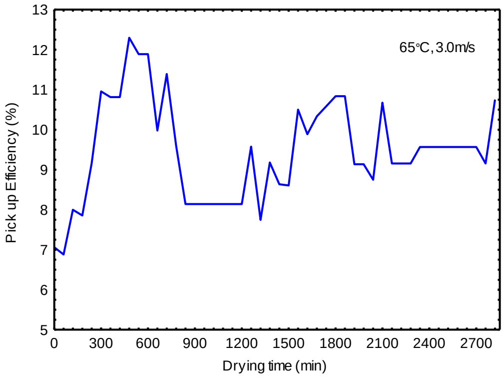
e: 55°C, 1.5m/s



f: 55°C, 3m/s



g: 65°C, 1.5m/s



h: 65°C, 3m/s

Figure 7: Pick-up efficiency vs. drying time

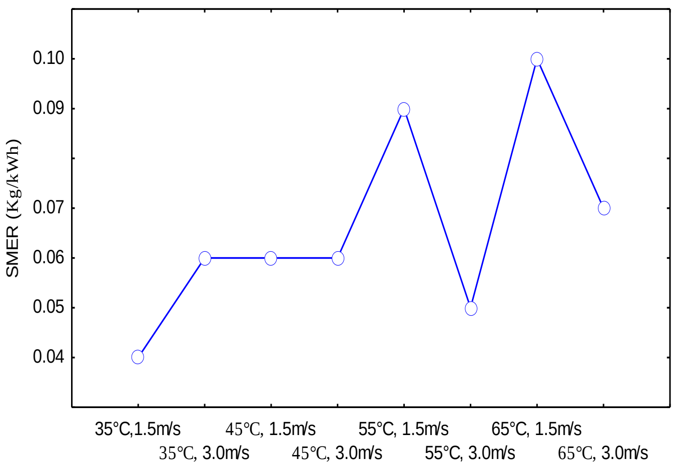


Figure 8: Specific-moisture extraction-rate

The average values of the specific moisture extraction rate (*SMER*) are varied between 0.04 - 0.10 (*l/kWh*), as it presented in Figure 8. Conventional hot-air drying of timber has a SMER value of 0.8-1.0 (*l/kWh*) (Brundrett, 1987). SMER of 0.55 and 0.82 (*l/kWh*) is found by in drying 20kg green-peas at airflow rates of 0.01 and 0.03 (kg/m^2s), respectively (Shanmugam and Natarajan, 2006). They obtained higher values because they used 20kg of green peas compared to ≈10kg of Roselle used in this study, as the SMER is positively related to the weight of material being dried (Hawlader and Jahangeer, 2006). Generally, the values of SMER tend to increase with the drying temperature.

At flow rates of 0.021 and 0.06kg/s, SMER values of 0.4262 and 0.3387kg/kWh are found, respectively by Hassan et al., (2023). Khanlari et al., (2020a), used a tubular solar air-dryer (greenhouse-dryer) at a flow rate of 0.015 kg/s and reported a SMER of 0.34 kg/kWh. A SMER value of 0.19 kg/kWh is obtained by Yahya, (2016), using a solar-assisted heat-pump dryer, and of 0.14 kg/kWh, by Yahya et al., (2016) using a solar-fluidized-bed dryer. Wang et al., (2019), achieved a SMER value of 2.05 kg/kWh, for drying mangoes in the solar-assisted heat pump system.

Specific-heat consumption (*SHC*) values are shown in Figure 9. The values are decreased as the drying-temperature was increased. This is because in drying Roselle at high temperatures (55°C and 65°C) the weight is reduced considerably in shorter times compared to that of low temperatures (Saeed et al., 2006). Consequently, the energy needed for regeneration of the silica gel columns, water pumping, etc., is reduced.

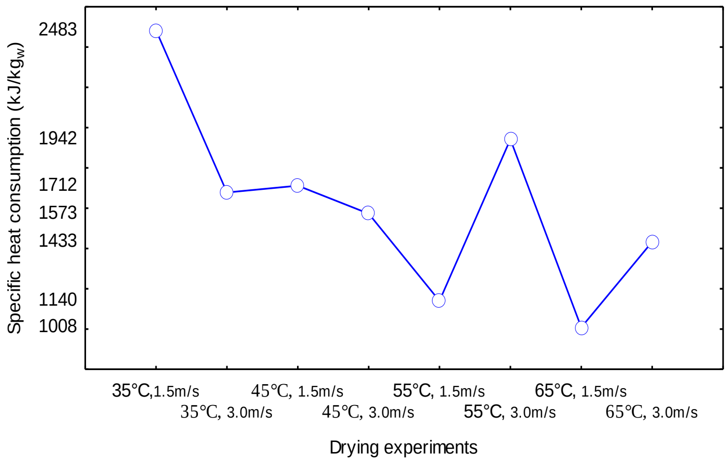


Figure 9: Specific heat consumption

The amount of energy supplied from solar collector is varied depending on the weather conditions. Higher energy is collected at higher insolation levels. The quantities of energy required by the drying process (Q_{load}), energy supplied from auxiliary heaters ($Q_{electric}$), and energy from the solar collector (Q_{solar}) are presented in Figure 10.

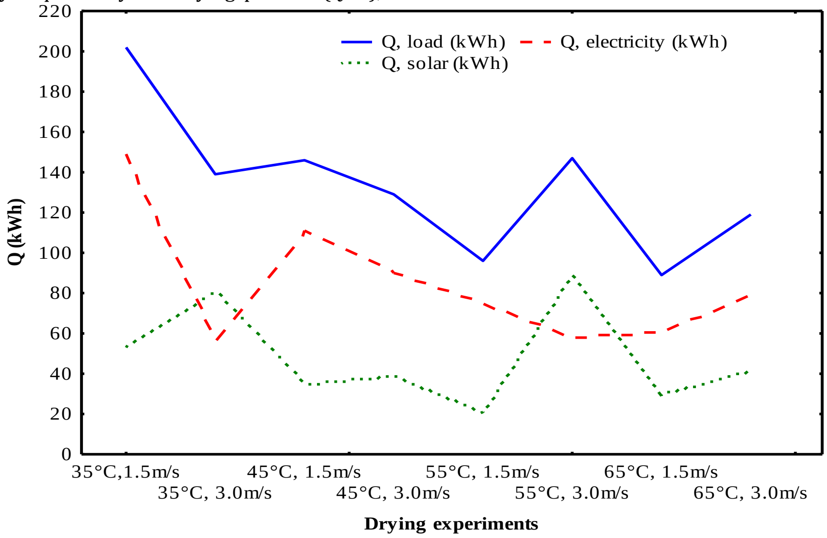


Figure 10: Q $_{load}$, Q $_{electricity}$, and Q $_{solar}$

Table 5 shows the drying and thermal efficiencies, coefficient of performance (*COP*), and energies from solar collector (Q_c), auxiliary heater (Q_e), and total energy Q_{total}. The Table also presents the SMER and SHC, and solar fraction (*f*).

In solar drying of Mango slices for 1030minutes, at inlet-temperature to the drying-cabinet of 45°C, found that the system consumed 27.8 kWh of power, with 33.4% drying system's efficiency (Wang et al., 2019). They also obtained *COP* for the entire system as 3.69. The average COP recorded by Hassan et al. (2023), are 2.515 and 3.004 at flow rate of 0.021 and 0.06 kg/s, respectively. Badescu et al., (2019), used a corrugated solar air-heater at flow of 0.011 kg/s, and attained a COP of 2.94. Hassan et al., (2023), observed that, the COP is elevated throughout the day, reaching its peak at noon with maximum solar radiation, and subsequently declined. This decline is attributed to the reduction in useful heat gain as solar radiation decreased, while power consumption remained constant, resulting in a lower COP post-noon. The latter is also reported by Khanlari et al., (2020b), as they observed a similar decrease in COP following peak solar radiation.

Table 5: Drying efficiencies, SMER, SHC, energy, and solar fraction

Drying experiments		η_{drying}	η_{Th}	COP	SMER	SHC	Q_c	Q_e	Q_{tot}	*f*
T(°C)	Air-Velocity	%	%	%	Kg/kWh	kJ/kg$_w$	kWh	kWh	kWh	%
35	1.5m/s	3.3	2.5	1.6	0.03	3981	48	275	323	15
	3.0m/s	3.1	3.4	2.1	0.03	2958	81	163	245	33
45	1.5m/s	3.8	3.8	2.4	0.04	2660	35	192	227	15
	3.0m/s	3.0	3.7	2.3	0.04	2700	51	170	222	23
55	1.5m/s	3.7	5.8	3.7	0.06	1722	21	124	146	15
	3.0m/s	2.7	3.9	2.5	0.04	2567	89	105	195	46
65	1.5m/s	3.1	7.4	4.7	0.07	1355	29	90	119	25
	3.0m/s	3.0	4.9	3.1	0.05	2043	41	129	170	24
Min.		2.7	2.5	1.6	0.03	1355	21	90	119	15
Max.		3.8	7.4	4.7	0.07	3981	89	275	323	46
Aver.		3.2	4.4	2.8	0.04	2498	50	156	206	25

4. Conclusions

The drying capacity and efficiencies are studied in this part of the thermal-analysis of solar-assisted drying-system. The evaporative-capacity is a moisture-content of the Roselle dependent. The mass shrinkage ratios are ranged between 0.105-0.153. Pickup efficiency is varied between 22.41 and 9.47%, in processing for 35°C, 3m/s and 65°C, 3m/s, respectively. The specific moisture extraction rate is found between 0.04 and 0.10 (*l/kWh*). An inverse relation is observed between the specific heat consumption and drying temperature, while, specific moisture extraction rate showed a positive relation with the drying temperature.

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