

Evaluation of the Novel Dehydration Concept for Wild Multi Floral Honey in Vietnam

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Dehydration of honey is an essential step during honey production in tropical countries to prevent rapid deterioration in quality because of the fermentation. In this study, honey dehydration at atmospheric pressure and temperatures of 36°C, 42°C, and 52°C in a pilot dehydration plant based on JEVA concept was carried out to reduce the moisture content of honey to below 17%. Honey dehydration at a temperature range of 36°C - 42°C achieved a high dehydration rate and low energy simultaneously due to integrating a heat pump into the processing loop. The temperature range of 36°C - 42°C was found out to be the most favourable processing temperature for honey dehydration since at these operational conditions, minimal colour degradation of honey, a low decline in diastase number and high retention of TPC and TFC (87.0% - 88.2% and 74.8% - 80.6%) were achieved. Moreover, honey samples dehydrated at 36°C and 42°C preserved antibacterial activity for strains of *MRSE*, *Salmonella Typhimurium*, *Proteus Vulgaris*, and *Pseudomonas aeruginosa* compared to raw honey. Under similar operational conditions, the proposed dehydration plant has been found to be better than that of other honey dehydrators reported in the literature in terms of dehydration rate, energy consumption, and lighter impacts on physicochemical characteristics.

1. Introduction

Honey (*Apis mellifera*) is a natural product from the flowers and leaf fluids of plants. In honey, reduced sugars (glucose, fructose) and water are the dominant substances (Council of the European Union, 2002). Besides, honey also contains vitamins, minerals, and bioactive compounds from phenolic and flavonoids groups (Yap et al., 2019). Honey is used as a nutritional food or as an aid in the treatment of digestive and respiratory ailments. The high moisture content in honey will combine with yeasts to create undesired by-products such as ethanol, CO₂, acetic acid, reducing the nutritional and sensory qualities (Dustmann, 1993). Sanz S. (1995) reported that the moisture content in honey below 17%wt. will inhibit the growth of yeasts, thereby limiting the fermentation. In recent years, the annual honey production of Vietnam has reached about 50,000-55,000 tons, which mainly serves the export. Domestic consumption accounts for only about 10% of total production. Due to climatic conditions, freshly harvested honey in Vietnam have exceptionally high moisture content (23-27 %wt.). Therefore, dehydration of honey is an essential step during honey production in Vietnam and other tropical countries to assure the quality and value of honey products.

Nevertheless, honey's dehydration is quite challenging and high energy-consuming process (Gill et al., 2015) due to its high bound moisture and viscosity. Different honey dehydration techniques using hot air, microwave and infrared heat (Subramanian et al., 2007) have been developed. Most of these technologies are conducted at high temperatures, causing colour degradation, an increase in 5-hydroxymethylfurfural content, and decreased diastase activity (Yap et al., 2019). Besides, the dehydration of honey can also be realized under vacuum pressure, enabling a reduction in operating temperature to 40°C - 45°C. Nevertheless, the operation at vacuum pressure did cause significant loss of the volatile compounds in honey (Cui et al., 2008). Gill et al. have developed an apparatus for dehydration of honey at atmospheric pressure and moderate temperature (Gill et

al., 2015). However, the dehydration rate of these systems was relatively low and combined with high energy consumption.

This research's objective was to evaluate process performance and the effect on physicochemical properties and biological activity of multiflora honey (from Hoa Binh province, Vietnam) of honey dehydration by the novel dehydration concept using dry air at moderate temperature and ambient pressure named JEVA.

2. Material and methods

2.1. Material

Multi-floral honey was harvested in Hoa Binh province, Vietnam. The sampling procedure was done according to AOAC 920.180 standard.

2.2. Dehydration batches

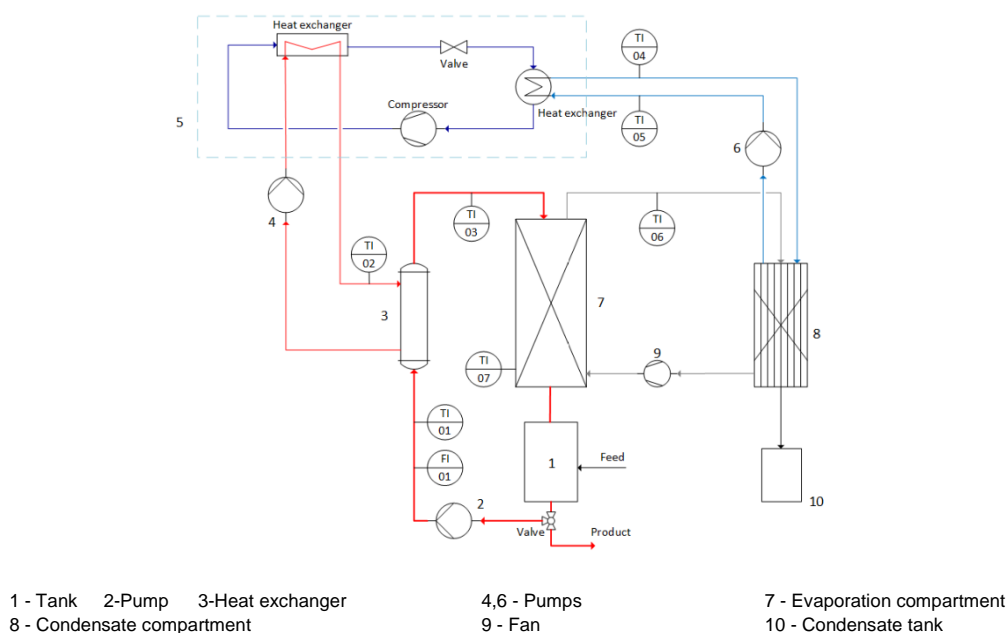


Fig. 1 Schematic diagram of the honey dehydration apparatus based on JEVA principle (Nguyen and Samhaber., 2018)

The dehydration process was carried out in a pilot dehydration plant, whose schematic diagram can be seen in Figure 1. For each dehydration batch, 10 kg raw honey was pumped into the tank (1) and lead to the heat exchanger (3) for warming up at a flow rate of 4.8 l/min. Honey was then transferred into the evaporation compartment (7) where water was evaporated. In this compartment, honey went from top to bottom; the air moved from the bottom up at a flow rate of 4 m/s. Water in honey was transferred to the vapour phase, which was carried through the condensate compartment (8). The condensate was then collected in the condensate tank (10). After a certain number of circulations, the water content in the honey was gradually decreased, and when it reached the required level, dehydrated honey was taken out and stored.

In this study, honey dehydration was performed at 36°C; 42 °C and 52 °C. In the experiments, physicochemical properties of raw honey and dehydrated honey were analyzed to evaluate the effect of dehydration on honey quality. The dehydration rate (kg water/hour) was calculated according to Chakraverty (1988). Besides, the whole plant's energy consumption (including pumps, compressors, etc.) was also recorded by the electric meter.

2.3. Physicochemical characterization

The moisture content in honey was determined according to AOAC 969.38B; 5-hydroxymethylfurfural (HMF) content and acidity were determined respectively according to AOAC 980.23 and AOAC 962.19; Diastase number (DN) was determined according to the AOAC 958.09. The sucrose and reducing sugar content were quantified according to AOAC 920.184 and AOAC 920.183 standards. The colour of honey samples was determined, according to Bulut et al. (2009). The pH value was determined by pH90 device (WTW, Germany). Total polyphenolic content (TPC) and total flavonoid content (TFC) was determined according to the methods

described by Georgé et al. (2005) and Marinova et al., 2005. The antioxidant activity of honey samples was determined using the DPPH reagent, and the absorbance measured at 517 nm (Chanda and Dave, 2009). Antimicrobial activity of honey samples was assessed by agar well diffusion assay (Zone of Inhibition Evaluation), minimum inhibitory concentration (MIC) for strains of MRSE, *Salmonella Typhimurium*, *Proteus Vulgaris* và *Pseudomonas aeruginosa*. The experimental procedure was conducted according to Chauhan et al. (2010).

2.4. Statistical analysis

All measurements were carried out in triplicate, and the data were expressed as means \pm standard deviations (SD). One-way ANOVA analysis was implemented. Tukey's test was used to verify for any significant differences among the mean values at confidence level $p < 0.05$.

3. Results and discussion

3.1. Dehydration rate and energy consumption

Table 1 showing an overview of the operating parameters of the honey dehydration process of different studies. The dehydration rate was 293.69 g water/h, 334.67 g water/h and 363.64 g water/h respectively at the process temperatures of 36°C, 42°C and 52°C. An increase in the process temperature led to a decrease in viscosity, a restriction on flocculation, and enhanced water diffusion into the drying agent (warm air), thereby increasing the dehydration rate. The dehydration plant proposed in this study allows reducing moisture content in honey from 25%wt. to less than 17% wt. at a temperature range between 36°C and 52°C. The moisture content in dehydrated honey met the European Union standard for honey (Council Directive 2001/110/EC.).

. Table 1: Operating parameters of honey dehydration from different studies

Honey dehydrators	Relative humidity of air (%)	Temperature of honey (°C)	Dehydration rate (g H ₂ O/h)	Energy consumption (kWh/kg honey)
This study	36-61	36 \pm 1	293.69 \pm 5.71	0.741 ^a \pm 0.021
		42 \pm 1	334.67 \pm 4.62	0.701 ^b \pm 0.014
		52 \pm 1	363.64 \pm 4.78	0.642 ^c \pm 0.027
Gill et al. (2015)	40-76	35	83.0	-
		40	177.0	0.94
Singh et al. (2011)	37-72	35	280.0	-
		40	317.2	2.90

The honey dehydrator system proposed by Gill et al. has a dehydration rate of 83g water/h at 35°C and 177g water/h at 40°C (Gill et al., 2015). The system proposed by Singh et al. had a dehydration rate of 280 and 317.2g water/h, respectively, at 35°C and 40°C (Singh et al., 2011). Table 1 emphasized quite clearly, that with honey dehydrators of Gill et al. and Singh et al., the compromise between high dehydration rate and low energy must be reached. On the contrary, honey dehydration at 42°C in the pilot dehydration plant proposed in this study achieved a high dehydration rate (334.67 g water/h) and low energy (0.701, kWh/kg honey) simultaneously. The 25-75% lower energy consumption than that of the apparatus developed by Singh et al. and Gill et al. was mainly contributed by the integration of a heat pump into the processing loop.

3.2. Physicochemical characterization

In this study, the reduced sugar content (fructose and glucose) in honey samples was about 70%wt.-71%wt. and was dominant compared to sucrose (approx. 2.08%wt. - 2.12%wt.). The difference in sucrose content among the honey samples was investigated was is not statistically significant ($p > 0.05$), while the reduced sugar content in dehydrated honey samples slightly increased compare to raw honey ($p < 0.05$).

Table 2. Moisture content, sugar content, pH and total acid content of honey samples

Name	Raw honey	Dehydrated honey at 36°C	Dehydrated honey at 42°C	Dehydrated honey at 52°C
Sample code	R. Honey	D. Honey. 36	D. Honey. 42	D. Honey. 52
Moisture content, %wt.	25.07 ^a \pm 0.12	16.77 ^b \pm 0.15	16.67 ^b \pm 0.15	16.63 ^b \pm 0.12
Total soluble solid, °Brix	74.83 ^a \pm 0.29	83.13 ^b \pm 0.15	83.37 ^b \pm 0.12	83.30 ^b \pm 0.15
Sucrose content, %wt.	2.08 ^a \pm 0.02	2.11 ^a \pm 0.02	2.11 ^a \pm 0.01	2.12 ^a \pm 0.01
Reduced sugar content, %wt.	70.14 ^a \pm 0.10	71.34 ^b \pm 0.13	71.38 ^b \pm 0.14	71.10 ^b \pm 0.07
pH	4.30 ^a \pm 0.02	4.06 ^b \pm 0.02	4.06 ^b \pm 0.02	4.07 ^b \pm 0.02

Total acid content, %wt.	0.522 ^a ± 0.003	0.579 ^b ± 0.005	0.578 ^b ± 0.003	0.577 ^b ± 0.003
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Results are given as mean ± SD (n = 3).

Different letters in the same row indicate a statistically significant difference (p < 0.05).

The pH value of raw honey samples (4.30^a ± 0.02) has higher than that of the dehydrated honey samples. This is because the removal of water in raw honey led to an increase in the concentration of organic acids. This is also reflected in the total acid content of dehydrated honey that a slight increase (approx. 10.54 %) compared to raw honey. Also, the difference in the pH value and in total acid content of the dehydrated honey samples was not statistically significant (p > 0.05), which shown that the dehydration processes carried out at a temperature range of 36°C - 52°C did not have a noticeable impact on the pH value and total acid content of honey.

Table 3 showed the results of the colour measurement of raw honey and dehydrated honey samples from dehydration batches carried out at temperatures 36°C, 42°C, and 52°C. The raw honey has 90.65 ± 0.43 mmPfund value in the Pfund scale. The dehydrated honey sample at 36°C and 42°C the results of 93.08 ± 0.84 and 96.61 ± 0.69 mmPfund (all three samples were amber). Conventionally, the colour degradation of honey after dehydration was caused by reduced water content (Yap et al., 2019), caramelization reactions, oxidation reactions in prolonged processing time and the Maillard reaction between amino acid compounds and polysaccharide (Ana et al., 2014). Base on the consideration of the sucrose content, reduced-sugars content in honey, the obtained results of this study pointed out that the dehydration at atmospheric pressure and a temperature range of 35-42°C helped to limit caramelization and Maillard reactions, avoiding colour degradation of honey.

Table 3. Change in colour of honey samples after dehydration at different conditions

Name	Raw honey	Dehydrated honey at 36°C	Dehydrated honey at 42°C	Dehydrated honey at 52°C
Sample code	R. Honey	D. Honey. 36	D. Honey. 42	D. Honey. 52
L*	15.89 ^a ± 1.04	9.44 ^b ± 0.45	9.13 ^b ± 0.13	2.48 ^c ± 0.06
a*	6.87 ^a ± 0.39	5.36 ^b ± 0.13	6.45 ^c ± 0.16	2.10 ^d ± 0.12
b*	21.66 ^a ± 1.20	12.32 ^b ± 0.98	13.48 ^b ± 0.75	1.83 ^c ± 0.19
mmPfund	90.65 ^a ± 0.43	93.08 ^b ± 0.84	96.61 ^c ± 0.69	114.60 ^d ± 1.3
Colour	Amber	Amber	Amber	Amber/ Dark amber

Results are given as mean ± SD (n = 3).

Different letters in the same row indicate a statistically significant difference (p < 0.05).

Colour of honey sample dehydrated at 52°C was 114.60 ± 1.3 mmPfund, 26,42% higher than that of the raw honey sample and 23.12% compared to the dehydrated honey sample at 36°C. In this case, in addition to the dehydration and oxidation, the reaction to form polymeric brown pigments began to occur, causing the honey to convert dark amber colour. In a similar study, Yap et al. (2019) reported a 23% and 61% increase in Kelelut honey colour intensity after being dehydrated at 40°C and 55°C for 72 hours. Cui et al. (2008) also reported that honey colour change was negligible at temperatures between 30°C and below 50°C, while Turkmen et al. (2006) reported that honey was darkened high degree of colouration at temperatures between 50°C and 70°C.

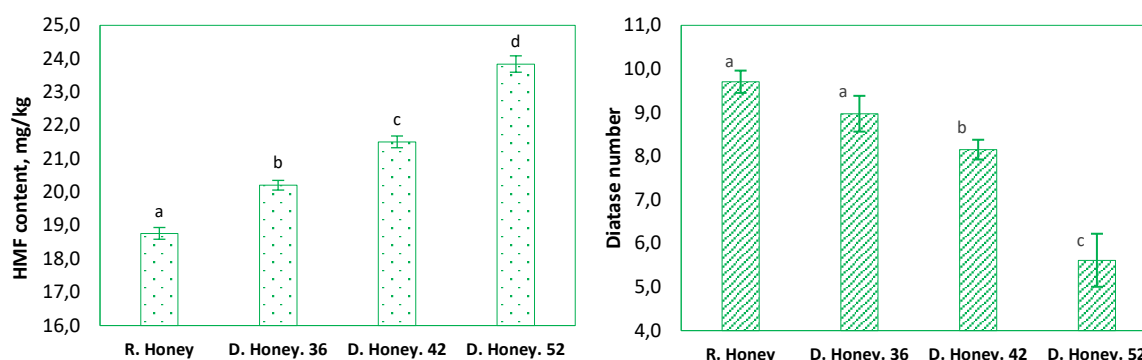


Fig 2. Effects of dehydration temperature on HMF content and diastase number of honey samples

5-hydroxymethylfurfural (HMF) is one of the most important parameters to assess honey quality and is closely correlated with the effects of heat treatment. Figure 2 shown that the HMF content of dehydrated honey samples processed at 36°C and 42°C was higher than that of raw honey 7.69 and 14.62%, respectively. In this case, the increase in HMF was mainly due to the thermal effect of the dehydration process. However, the HMF content of honey samples dehydrated at 52°C was 23.80 ± 0.25 mg/kg, 27.1% higher than that of raw honey; the reason

was that higher temperature increased the rate of reaction forming HMF. Yap et al. (2019) reported that there was no significant change in HMF content when the dehydration of Kelelut honey at 40°C, but at 55°C there was an increase in the HMF content in Kelelut honey from about 4.mg/kg to more than 50 mg/kg after 72 hours. The HMF can cause cancer, so the formation of HMF must be tightly controlled and restricted. The European Union required that the HMF content not exceed 80 mg/kg for honey from tropical countries. HMF content of all the obtained dehydrated honey samples in this study was within the permitted limits.

Diastase number (DN), which is characteristic of the activity of the α - and β -amylase enzymes in honey, was significantly reduced during thermal treatment (Chua et al., 1994). This study showed that the diastase number of raw honey was 9.71 ± 0.26 and decreased to 8.97 ± 0.41 for dehydrated honey at 36°C and 8.15 ± 0.23 for the dehydrated honey at 42°C, respectively. White et al. (1994) observed that a decrease in diastase activity could occur even at relatively low temperatures. The honey samples dehydrated at 52°C have a DN of 5.58 ± 0.46 , which was not the E.U. honey standard (DN is not lower than 8.0). Therefore, in terms of DN, the dehydration performed at atmospheric pressure and temperature range of 36°C - 42°C were just efficient.

Effect of the dehydration process on TPC and TFC in honey was also examined (Table 4). The retention of TPC and TFC after dehydration were determined by comparing TPC and TFC of raw honey and dehydrated honey (taking the TPC and TFC of raw honey as 100%). Retention of polyphenol, flavonoid compounds in dehydrated honey at 36°C and 42°C was in the range of 87.0% - 88.2% and 74.8% - 80.6%, respectively, while the dehydrated honey at 52°C had a TPC and TFC of 209.24 ± 1.94 mgGAE/kg and 8.3 ± 0.23 mgQE/kg lower than honey samples were dehydrated at 36°C and 42°C.

Table 4. Effects of dehydration temperature on TPC, TFC and antioxidant activity of honey

Name	Raw honey	Dehydrated honey at 36 °C	Dehydrated honey at 42 °C	Dehydrated honey at 52 °C
Sample code	R. Honey	D. Honey. 36	D. Honey. 42	D. Honey. 2
TPC, mgGAE/100g	$228.57^a \pm 1.68$	$222.88^b \pm 1.71$	$219.94^c \pm 1.5$	$209.24^d \pm 1.94$
Polyphenol retention after dehydration, %	-	88.2	87.0	82.79
TFC, mgQE/100g	$10.90^a \pm 0.32$	$9.71^b \pm 0.18$	$9.01^c \pm 0.16$	$8.3^d \pm 0.23$
Flavonoid retention after dehydration, %	-	80.6	74.1	68.8
DPPH radical scavenging activity (%RSA)	$52.58^a \pm 0.13$	$50.13^b \pm 0.25$	$47.67^c \pm 0.62$	$42.71^d \pm 0.39$

Results are given as mean \pm SD (n = 3).

Different letters in the same row indicate a statistically significant difference (p <0.05)

The decline in the TPC and TFC of honey samples dehydrated at 52°C resulted in lower antioxidant activity than raw honey samples and honey samples dehydrated at 36°C and 42°C.

Table 5. Zone of inhibition and minimum inhibitory concentration of honey samples for strains

Samples	R. Honey		D. Honey. 36		D. Honey. 42		D. Honey. 52	
	Zone of Inhibition (mm)	MIC (g/ml)	Zone of Inhibition (mm)	MIC (g/ml)	Zone of Inhibition (mm)	MIC (g/ml)	Zone of Inhibition (mm)	MIC (g/ml)
MRSE (ATCC 35984)	13.0 \pm 0.58	0.25 \pm 0.00	14.17 \pm 0.76	0.25 \pm 0.00	13.83 \pm 0.58	0.25 \pm 0.00	11.83 \pm 0.30	0.75 \pm 0.06
Salmonella Typhimurium (ATCC 14028)	16.8 \pm 0.76	0.25 \pm 0.00	16.8 \pm 0.58	0.25 \pm 0.06	17.33 \pm 0.76	0.25 \pm 0.56	14.21 \pm 0.56	0.5 \pm 0.06
Proteus vulgaris (ATCC 49132)	16.3 \pm 0.58	0.25 \pm 0.00	17.5 \pm 1.53	0.25 \pm 0.56	17.5 \pm 0.76	0.25 \pm 0.56	14.5 \pm 0.58	0.5 \pm 0.56
E. Coli (ATCC 25922)	13.5 \pm 0.76	0.25 \pm 0.00	10.5 \pm 0.58	0.5 \pm 0.00	9.5 \pm 0.56	0.5 \pm 0.06	8.5 \pm 0.29	0.9 \pm 0.14
Pseudomonas aeruginosa (ATCC 9027)	16.5 \pm 1.00	0.25 \pm 0.00	14.5 \pm 0.76	0.25 \pm 0.06	15.5 \pm 0.76	0.25 \pm 0.06	10.5 \pm 0.58	0.75 \pm 0.06

The antibacterial activity of honey is related to the activity of the enzyme glucose oxidase and catalase (White et al.,1963). Honey has been used to treat wounds and to aid in the treatment of digestive and respiratory ailments. Recently, honey has also been studied to contribute to the increased shelf life of fresh milk (Kurrhna et al., 2007) and chicken slices (Kalyoubi et al., 2014) due to their natural antimicrobial action. Table 5 shows the diameters of bacterial inhibition and minimum inhibitory concentration (MIC) of honey samples. The results

showed that honey samples dehydrated at 36°C and 42°C preserved antibacterial activity for strains of *MRSE*, *Salmonella Typhimurium*, *Proteus vulgaris*, and *Pseudomonas aeruginosa* compared to raw honey. A sharp decrease in antibacterial activity, reflected in the decreasing zone of inhibition size and increasing MIC values, was observed in the honey sample dehydrated at 52°C. High temperatures are detrimental to the activity of the enzyme glucose oxidase, White and Subers (1964) reported that heating at 50°C for 20 min decreased the activity of the enzyme glucose oxidase. It pointed out that the selection of operational conditions for honey dehydration played a critical role in ensuring quality honey using in the food, cosmetic, and pharmaceutical industries.

4. Conclusions

Honey dehydration at atmospheric pressure and temperatures of 36°C, 42°C, and 52°C in a pilot dehydration plant based on JEVA concept was carried out to reduce the moisture content of honey to below 17%. Honey dehydration at the temperature range of 36°C - 42°C achieved high dehydration rate and low energy simultaneously due to integrating a heat pump into the processing loop. The dehydrated honey met E.U. honey standard (Council Directive 2001/110/E.C.) in its every category (moisture content, HMF content, Diastase number, Sucrose content, reduced sugar content, pH, etc.). The temperature range of 36°C - 42°C was found out to be the most favourable processing temperature for honey dehydration since at these operational conditions, minimal colour degradation of honey, a low decline in diastase number and high retention of TPC and TFC (87.0% - 88.2% and 74.8% - 80.6%) were achieved. Moreover, honey samples dehydrated at 36°C and 42°C preserved antibacterial activity for strains of *MRSE*, *Salmonella Typhimurium*, *Proteus vulgaris*, and *Pseudomonas aeruginosa* compared to raw honey. Under similar operational conditions, the proposed dehydration plant has been found to be better than that of other honey dehydrators reported in the literature in terms of dehydration rate, energy consumption, and minor impacts on physicochemical characteristics.

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