

Honey adulteration in the Philippines after the adoption of the ISCIRA method in the national standard

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ABSTRACT

Honey adulteration is the addition of exogenous sugars to harvested honey, usually done for economic gains. A 2021 study determined that 76 out of 90 (84.4%) local honey products sold in the Philippine market (store and online-bought) are adulterated (Lao et al. 2021). This emphasizes the need for a robust guideline to detect fraudulent honey products for the benefit of consumers, in both economic and health terms. In response, the Philippine National Standards (PNS/BAFS 185:2022) for Honey was revised in 2022 to include stable carbon isotope ratio analysis (ISCIRA), as proposed by DOST-PNRI. This work explores the current state of honey adulteration in the Philippine market as a follow-up to the initial study conducted in 2021. The analytical process followed the validated ISCIRA utilized in the previous market survey. 102 honey samples were obtained from physical retail outlets across various regions in the Philippines, comprising 86 local and 16 imported products. Of these, 58 of 86 (67.4%) local and four of 16 (25.0%) imported samples were classified as non-compliant with the ISCIRA authenticity criteria. Overall, 62 of 102 (60.8%) samples were non-compliant, which was comparable with the 58.0% overall adulteration rate in the 2021 study. Among the non-compliant samples, 39 (62.9%) yielded no extractable protein, while 55 contained >75% apparent C4 sugar content, including 45 samples estimated to be fully substituted by C4 adulterants. These findings underscore the need to strengthen the implementation of the revised Philippine National Standard for honey through sustained market surveillance, regulatory enforcement, and complementary rapid-screening tools.

INTRODUCTION

Pure honey is defined as the naturally sweet substance produced by bees using nectar collected from flowering plants (Thrasyvoulou et al. 2018). The nectar is processed in the bee hive, mixed with enzymes secreted by bees, and matured to produce honey. It serves as a method of storing food for the bees to be consumed during harsh climates. Its sweet taste gives it widespread culinary use and high market demand. Due to its profitability, various entities resort to adding exogenous sugars commonly from cane and corn syrup into honey products to increase their income – a practice called honey adulteration. In its pure form, honey offers a variety of health benefits due to its antioxidant and antiseptic properties (Mandal & Mandal 2011). However, the adulteration of its products can reverse its supposed nutritional benefits and may introduce health risks to its consumers (Tosun 2013). Aside from the risks posed by this practice, it also places an economic strain on the livelihoods of authentic honey farmers and tolerates malpractice in product marketing.

Multiple methods for authenticating honey products have emerged over time. However, most of these rely on physicochemical parameters that cannot differentiate the similar characteristics of sugars from legitimate honey against fraudulent sources, making them unreliable (Bogdanov et al. 1999). To address this gap, Lao et al. (2021) demonstrated the feasibility of using the Internal Standard Stable Carbon Isotope Ratio Analysis (ISCIRA) to assess the authenticity of Philippine honey (Table 1). This method offers the most reliable approach for authenticating honey from C4 adulteration yet, and determining its effectiveness can lead to better regulation and metrics that may be adopted by the industry and monitored by the public. The technique relies on the difference between the carbon isotopes found in nectar collected by honeybees (commonly from C3 plants) and in exogenous sugars (usually from cane and corn, which have C4 metabolism). In C3

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KEYWORDS

Food authenticity, stable isotopes, $\delta^{13}\text{C}$ isotope ratio, mass spectrometry, nuclear technique

plants, the lighter isotope ^{12}C is more predominant relative to the heavier ^{13}C , making its $\delta^{13}\text{C}$ value between -32 and -21% in comparison to C_4 plants, which have values around -19 to -12% (Padovan et al. 2003). The isotope ratio determined from the bulk honey is then compared with that of the protein extracted from the honey. Natural bee enzymes may get incorporated with the honey during its production, and its carbon signature must be similar to the honey itself as the bees sourced their nectar from the same origin. In essence, the carbon signature of the bulk honey and the extracted protein of an authentic honey product must be close to or identical with each other. Adulteration shifts the carbon signature of the honey but not of the protein mixed within, making the protein's carbon isotope ratio a reliable identifier of C_4 adulteration. The ISCIRA index, or the difference between the carbon signatures of the protein and bulk honey ($\delta^{13}\text{C}_{\text{protein}} - \delta^{13}\text{C}_{\text{bulk honey}}$), must be greater than or equal to -1% to render a honey product authentic (White & Winters 1989). As such, the use of ISCIRA and $\delta^{13}\text{C}$ analysis have proven effective in detecting C_4 sugar adulteration in honey but are less suitable for detecting C_3 adulterants (i.e., rice, wheat, and beet-derived sugars) because their $\delta^{13}\text{C}$ values overlap with those of authentic honey (Geană et al., 2020).

Table 1: Carbon Isotope Ratio of authentic honey as per PNS/BAFS 185:2022

Parameter	Carbon stable isotope ratio limit
$\delta^{13}\text{C}_{\text{protein}} - \delta^{13}\text{C}_{\text{bulk honey}}$	Not less than -1%
Bulk $\delta^{13}\text{C}$	Not more than -19.2% , VPDB

In the 2021 study by Lao et al., 75.0% (12 of 16) of local store-bought and 86.5% (64 of 74) of local online-bought honey samples were adulterated with C_4 sugars. Among these adulterated samples, 93.4% contained more than 78.0% apparent C_4 sugar. Given the high demand for honey products in the Philippines, these findings underscore the need to develop methods and safeguards to ensure honey authenticity. A year later, parameters based on Lao's study were adopted into the Philippine National Standard for Honey (PNS/BAFS 185:2022), providing a reliable guideline in honey safekeeping.

However, the practical adoption of PNS/BAFS 185:2022 remains constrained. According to the Department of Agriculture – Bureau of Agriculture and Fisheries Standards (DA-BAFS), PNSs function primarily as technical benchmarks for related regulations, meaning compliance is voluntary unless explicitly mandated by a regulatory authority. In the absence of a mandatory conformity assessment scheme or systematic market-surveillance framework requiring commercial honey to demonstrate compliance with these authenticity provisions, substantial regulatory gaps still persist. Building on the findings of Lao et al. (2021), this study assessed locally produced and imported honey products available to consumers from different physical market sources across several regions in the Philippines to provide an updated baseline of C_4 sugar adulteration following the widespread public attention generated by the earlier study, and the September 2022 revision of the Philippine National Standard for honey to formally adopt the ISCIRA method.

MATERIALS AND METHODS

Sample collection

From 2022 to 2024, a total of 102 store-bought samples across several regions in the Philippines were collected for authenticity testing (Table 2). The samples were purchased from different physical retail outlets, including supermarkets, local wet markets, souvenir shops, and roadside vendors, and were packaged in various types of containers. Among the 102 samples collected for

this study, 86 were locally produced and 16 were imported based on the product label. Figure 1 shows the regional geographic distribution of the locations where the honey samples were produced according to their labels, while Table 2 presents the number of samples collected from each region. Sampling was based on the availability of honey products in the surveyed markets and was not proportionally distributed across regions, with Region IV-A having the largest representation ($n = 31$). Thus, the samples represent available commercial honey products from different regions rather than a nationally representative sample of the Philippine honey market.

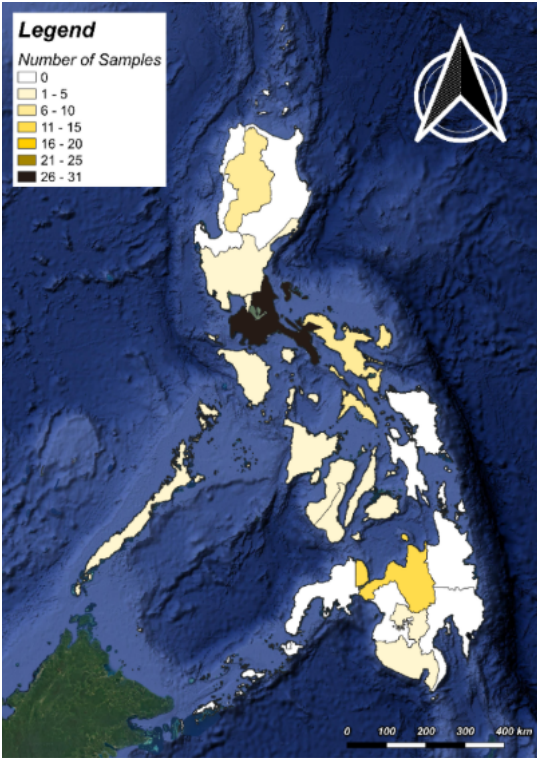


Figure 1: Distribution map of collected honey market samples

Table 2: Number of collected samples per region

Region	Samples
I	1
III	2
IV-A	31
IV-B	6
V	8
VI	5
VII	3
IX	1
X	13
XI	1
XII	2
CAR	9
NCR	3
Imported	16
Unknown local	1
TOTAL	102

Protein extraction

The protein extraction process followed the AOAC 998.12 method and as prescribed by PNS/BAFS 185:2022. Around 10-12 g of bulk honey sample was weighed into a 50 mL centrifuge tube and diluted with 4 mL ultrapure water (18.2 MΩ-cm resistivity). This was followed by the addition of 2 mL each of 10% Na₂WO₄ and 0.35 M H₂SO₄. The resulting solution was vortexed and heated at 80°C for 30 minutes and checked for the formation of protein precipitates. If no precipitate is found, 2 mL of 0.35 M H₂SO₄ is added until a precipitate forms for a maximum of five attempts. If there is still no precipitation, the sample is considered to have negligible extractable protein content. Solutions with precipitates were diluted to 50 mL using ultrapure water and centrifuged at 9000 rpm for 5 min (Hermle Z366). The supernatant was decanted off, leaving the protein, which was washed using 50 mL ultrapure water, centrifuged at 9000 rpm for 5 min, and its supernatant decanted off another five times. The protein is then freeze-dried, transferred to a 2 mL microcentrifuge tube and stored in a desiccator. For 10-12 g of honey sample, there must be at least 1 mg of precipitated protein. Otherwise, the extracted protein is considered negligible (Dong et al., 2018).

Measurement of $\delta^{13}\text{C}$ in bulk honey and protein

Approximately 300 ± 30 µg of bulk honey and its extracted protein was weighed into a 6 x 4 mm tin capsule using a Sartorius M3P microbalance and secured through folding. Their $\delta^{13}\text{C}$ were measured using a Sercon 20-22 Isotope Ratio Mass Spectrometer (IRMS) connected to a Sercon GSL sample preparation system (Sercon Limited, UK). A two-point linear normalization method referenced to several USGS standards was used to calculate the $\delta^{13}\text{C}$ of the samples. USGS 64 (glycine, $\delta^{13}\text{C} = -40.81\text{‰}$) and USGS 74 (L-threonine, $\delta^{13}\text{C} = -9.30\text{‰}$) were used as calibration standards for $\delta^{13}\text{C}$ analysis, while USGS 40 (L-glutamic acid, $\delta^{13}\text{C} = -26.39\text{‰}$) was used as the verification standard. Blank tin capsules and dummy honey samples were included in the analysis. Equation 1 shows the derivation of the sample's $\delta^{13}\text{C}$ using the generated calibration curve.

$$(1) \quad \delta^{13}\text{C}_{\text{sample, calculated}} = m \cdot \delta^{13}\text{C}_{\text{sample, raw}} + b$$

where:

$$(2) \quad m = \frac{\delta^{13}\text{C}_{\text{calib2, true}} - \delta^{13}\text{C}_{\text{calib1, true}}}{\delta^{13}\text{C}_{\text{calib2, raw}} - \delta^{13}\text{C}_{\text{calib1, raw}}}$$

and

$$(3) \quad b = \delta^{13}\text{C}_{\text{calib1, true}} - m \cdot \delta^{13}\text{C}_{\text{calib1, raw}}$$

RESULTS AND DISCUSSION

$\delta^{13}\text{C}$ measurements

Based on the criteria described by ISCIRA ($\delta^{13}\text{C}_{\text{bulk honey}} < -19.2\text{‰}$; extractable protein ≥ 1 mg per 10-12 g bulk honey; as $\delta^{13}\text{C}_{\text{protein}} - \delta^{13}\text{C}_{\text{bulk honey}} \geq -1\text{‰}$), only 40 out of 102 samples (39.2%) were classified as ISCIRA-compliant, corresponding to an apparent honey adulteration rate of about 60.8% (62 of 102) during the time of the study. Figure 2 shows the relationship between $\delta^{13}\text{C}_{\text{bulk honey}}$ and $\delta^{13}\text{C}_{\text{protein}}$ for all analyzed samples. The solid diagonal line represents the 1:1 relationship, while the dashed boundary lines indicate the $\pm 1\text{‰}$ range for the ISCIRA index. The compliant samples plotted within the bounded region and below the -19.2‰ $\delta^{13}\text{C}_{\text{bulk honey}}$ threshold, clustering within the “authentic zone.”

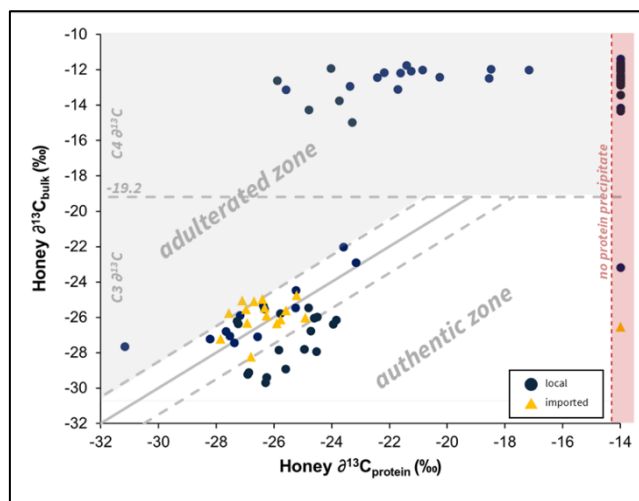


Figure 2: Scatter plot of the $\delta^{13}\text{C}_{\text{bulk honey}}$ and $\delta^{13}\text{C}_{\text{protein}}$ samples

Among the 62 non-compliant samples, 55 failed the first criterion by showing enriched $\delta^{13}\text{C}_{\text{bulk honey}}$ values above the -19.2‰ line, consistent with the possible addition or complete substitution of C4 sugar adulterants. In addition, 39 samples failed the second criterion because no precipitated protein was recovered during extraction. This scenario commonly occurs when the sample is only pure sugar syrup from corn or sugarcane. Since protein recovery is necessary for $\delta^{13}\text{C}_{\text{protein}}$ determination and ISCIRA index calculation, these samples were assigned an arbitrary plotting position at the extreme right of the graph for visualization and are highlighted in red.

Notably, two of the 39 samples with no extractable protein still showed depleted $\delta^{13}\text{C}_{\text{bulk honey}}$ values within the expected C3 isotope range of authentic honey. As previously mentioned, honey protein serves as the internal isotopic standard in ISCIRA. Thus, the absence of recoverable protein prevents calculation of the ISCIRA index and consequently fails the second criterion. Similar cases have been reported wherein honey samples with C3-like $\delta^{13}\text{C}_{\text{bulk honey}}$ values but no recoverable protein were likely to be adulterated with C3-derived sugars such as beet sugar (Simsek et al., 2012). Thus, while the exact nature of adulteration in these two samples cannot be resolved by ISCIRA since it is primarily designed to detect C4-derived adulteration, their C3-like bulk signatures together with the absence of recoverable protein may suggest possible C3-derived adulteration. Complementary analytical techniques such as LC-IRMS would be needed for further confirmation.

Moreover, five samples with extractable protein failed the third criterion by plotting outside the -1‰ acceptance range for the ISCIRA Index (i.e., left side of the left diagonal boundary line), indicating a mismatch between the isotopic compositions of bulk honey and honey protein. This scenario occurs when a honey sample is partially adulterated with sugar syrup from corn or sugarcane. Honey harvested from bees fed with C4 sugars also falls under this category.

This separation was further reflected in the $\delta^{13}\text{C}$ values of the compliant and non-compliant samples. For ISCIRA-compliant samples, $\delta^{13}\text{C}_{\text{bulk honey}}$ ranged from -29.70‰ to -22.90‰ , with a mean value of -26.56‰ , while $\delta^{13}\text{C}_{\text{protein}}$ ranged from -28.22‰ to -23.16‰ , with a mean value of -26.00‰ . These are all within the documented $\delta^{13}\text{C}$ range for authentic honey or C3 plants. In contrast, non-compliant samples with recovered protein showed wider and generally more enriched $\delta^{13}\text{C}_{\text{bulk honey}}$ values, ranging from -27.65‰ to -11.38‰ , with a mean value of -13.83‰ . Their corresponding $\delta^{13}\text{C}_{\text{protein}}$ values ranged from -31.17‰ to

-17.17%, with a mean value of -23.16%. The enriched, less negative bulk $\delta^{13}\text{C}$ values in most non-compliant samples are consistent with the possible addition of C4 sugar adulterants.

%C4 sugar content

Equation 4 was used to calculate the apparent C4 sugar content of the honey samples determined to be adulterated, where a value of $-12.28 \pm 0.25\text{‰}$ for the $\delta^{13}\text{C}_{\text{adulterant}}$ was used based on the mean $\delta^{13}\text{C}\text{‰}$ values of Philippine cane sugar-based sweeteners (Lao et al., 2021). Out of the 62 adulterated samples, 55 (88.7%) had an apparent C4 sugar content greater than 75%, of which 45 samples were found to be completely substituted with C4 sugar alternatives. This indicates that most of the adulterated samples detected in the present study were composed predominantly of C4-derived sugars rather than authentic honey with only small amounts of C4 adulterants added. Figure 3 shows a bar graph tallying the number of samples according to their apparent C4 sugar content.

(4) $\%C4\text{ sugar} = \frac{\delta^{13}\text{C}_{\text{honey protein}} - \delta^{13}\text{C}_{\text{bulk honey}}}{\delta^{13}\text{C}_{\text{honey protein}} - \delta^{13}\text{C}_{\text{adulterant}}} \times 100\%$

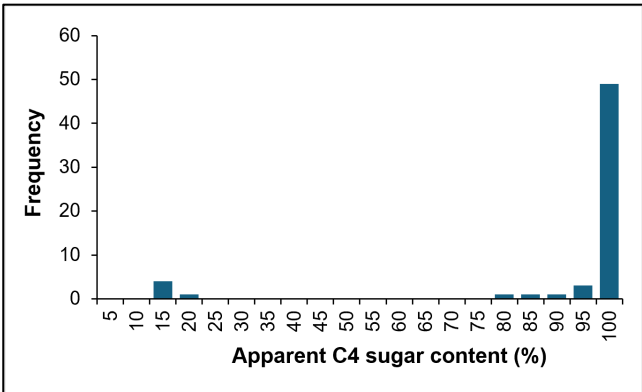


Figure 3: Apparent C4 sugar content of honey samples

compared with those reported in the 2021 market survey of Lao et al. (2021). One notable difference between the present study and the 2021 study is the sampling coverage. While the 2021 study sampled locally produced honey from both physical retail stores (n = 16) and online platforms (n = 74), the present study conducted a more extensive market survey of physical retail outlets (n = 86). To account for these sampling variations, comparative analyses were based around three broad categories: (1) local, (2) imported, and (3) total market honey samples. Figure 4 shows a summary comparing the percentages of authentic and adulterated honey samples in the 2021 study and the present work. Table 3 presents the list of market samples collected in the study, their corresponding $\delta^{13}\text{C}_{\text{bulk honey}}$ and $\delta^{13}\text{C}_{\text{protein}}$ values, ISCIRA indices, origin classification (i.e., local or imported), and apparent C4 sugar contents.

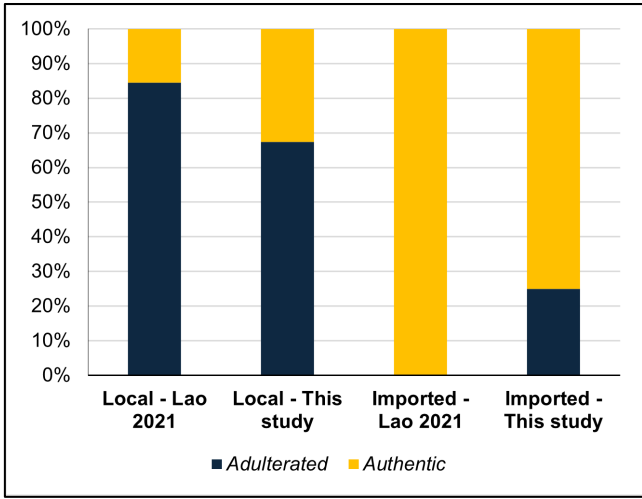


Figure 4: Comparison of results between Lao et al., 2021 and this work

Comparison with the 2021 market study

To contextualize the present findings and better understand their implications for the Philippine honey market, the results were

Table 3: Analytical results summary of the honey samples

Sample Code	$\delta^{13}\text{C}_{\text{bulk honey}}$		$\delta^{13}\text{C}_{\text{protein}}$		ISCIRA Index	Classification	Origin	Apparent C4 sugar content (%)
	Mean	SD	Mean	SD				
SB-A1	-11.80	0.15	NEP	NEP	NEP	Adulterated	Local	100%
SB-B1	-27.65	0.04	-31.17	0.07	-4	Adulterated	Local	19%
SB-B2	-25.10	0.17	-26.69	0.12	-2	Adulterated	Imported	11%
SB-B3	-25.06	0.03	-27.10	0.28	-2	Adulterated	Imported	14%
SB-B4	-26.31	0.03	-26.93	0.02	-1	C4 sugar-free	Imported	4%
SB-B5	-25.55	0.20	-26.97	0.54	-1	C4 sugar-free	Imported	10%
SB-B6	-25.61	0.14	-25.58	0.96	0	C4 sugar-free	Imported	0%
SB-B7	-26.13	0.11	-25.77	0.50	0	C4 sugar-free	Imported	0%
SB-Ba1	-12.42	0.20	-20.27	0.50	-8	Adulterated	Local	98%
SB-Ba2	-12.47	0.11	-18.55	0.23	-6	Adulterated	Local	97%
SB-Ba3	-12.43	0.08	-22.43	0.12	-10	Adulterated	Local	99%
SB-Ba4	-13.12	0.41	-25.58	0.85	-12	Adulterated	Local	94%
SB-Ba5	-25.45	0.14	-25.26	0.19	0	C4 sugar-free	Local	0%
SB-Ba6	-11.97	0.15	-18.48	0.44	-7	Adulterated	Local	100%
SB-Ba7	-12.01	0.06	-17.17	0.33	-5	Adulterated	Local	100%
SB-Ba8	-13.11	0.38	-21.71	0.12	-9	Adulterated	Local	91%
SB-Ba9	-12.07	0.23	-21.26	0.73	-9	Adulterated	Local	100%
SB-Ba10	-12.05	0.09	NEP	NEP	NEP	Adulterated	Local	100%
SB-Ba11	-14.16	0.03	NEP	NEP	NEP	Adulterated	Local	100%
SB-Ba12	-11.89	0.16	NEP	NEP	NEP	Adulterated	Local	100%
SB-Ba13	-11.96	0.03	NEP	NEP	NEP	Adulterated	Local	100%
SB-Ba14	-11.91	0.17	NEP	NEP	NEP	Adulterated	Local	100%

<i>SB-Bo1</i>	-12.37	0.07	NEP	NEP	NEP	Adulterated	Local	100%
<i>SB-Bo2</i>	-12.53	0.11	NEP	NEP	NEP	Adulterated	Local	100%
<i>SB-C1</i>	-11.74	0.00	-21.41	0.74	-10	Adulterated	Local	100%
<i>SB-C2</i>	-23.18	0.05	NEP	NEP	NEP	Adulterated	Local	- ^a
<i>SB-C3</i>	-22.90	0.04	-23.16	0.26	0	C4 sugar-free	Local	2%
<i>SB-CS1</i>	-12.00	0.09	-20.85	0.61	-9	Adulterated	Local	100%
<i>SB-I1</i>	-11.84	0.09	NEP	NEP	NEP	Adulterated	Local	100%
<i>SB-I2</i>	-24.96	0.10	-26.41	0.65	-1	C4 sugar-free	Imported	10%
<i>SB-I3</i>	-25.75	0.23	-27.56	0.57	-2	Adulterated	Imported	12%
<i>SB-I4</i>	-27.21	0.11	-27.86	0.10	-1	C4 sugar-free	Imported	4%
<i>SB-I5</i>	-25.46	0.14	-26.33	0.57	-1	C4 sugar-free	Imported	6%
<i>SB-I6</i>	-24.74	0.08	-25.22	0.09	0	C4 sugar-free	Imported	4%
<i>SB-I7</i>	-27.09	0.06	-26.57	0.72	1	C4 sugar-free	Local	0%
<i>SB-I8</i>	-25.92	0.07	-26.25	0.37	0	C4 sugar-free	Imported	2%
<i>SB-I9</i>	-26.53	0.04	NEP	NEP	NEP	Adulterated	Imported	- ^a
<i>SB-I10</i>	-11.95	0.11	NEP	NEP	NEP	Adulterated	Local	100%
<i>SB-I11</i>	-11.94	0.03	NEP	NEP	NEP	Adulterated	Local	100%
<i>SB-I12</i>	-11.78	0.03	NEP	NEP	NEP	Adulterated	Local	100%
<i>SB-I13</i>	-12.33	0.13	NEP	NEP	NEP	Adulterated	Local	100%
<i>SB-I14</i>	-24.47	0.01	-25.24	0.08	-1	C4 sugar-free	Local	6%
<i>SB-L1</i>	-11.92	0.02	NEP	NEP	NEP	Adulterated	Local	100%
<i>SB-L2</i>	-12.84	0.00	NEP	NEP	NEP	Adulterated	Local	100%
<i>SB-L3</i>	-11.79	0.15	NEP	NEP	NEP	Adulterated	Local	100%
<i>SB-L4</i>	-26.79	0.02	-27.67	0.26	-1	C4 sugar-free	Local	6%
<i>SB-M1</i>	-11.58	0.23	NEP	NEP	NEP	Adulterated	Local	100%
<i>SB-MT1</i>	-25.33	0.16	-26.38	0.44	-1	C4 sugar-free	Local	7%
<i>SB-MT2</i>	-25.89	0.02	-27.17	0.37	-1	C4 sugar-free	Local	9%
<i>SB-MT3</i>	-27.22	0.10	-28.22	0.35	-1	C4 sugar-free	Local	6%
<i>SB-MT4</i>	-27.43	0.02	-27.38	0.45	0	C4 sugar-free	Local	0%
<i>SB-MT5</i>	-12.94	0.18	-23.37	0.26	-10	Adulterated	Local	94%
<i>SB-MT6</i>	-12.16	0.16	-22.19	0.20	-10	Adulterated	Local	100%
<i>SB-MT7</i>	-12.18	0.19	-21.62	0.60	-9	Adulterated	Local	100%
<i>SB-MT8</i>	-11.64	0.04	NEP	NEP	NEP	Adulterated	Local	100%
<i>SB-MT9</i>	-27.05	0.14	-27.54	0.38	0	C4 sugar-free	Local	3%
<i>SB-NOc1</i>	-12.03	0.04	NEP	NEP	NEP	Adulterated	Local	100%
<i>SB-NOc2</i>	-12.46	0.02	NEP	NEP	NEP	Adulterated	Local	100%
<i>SB-QC1</i>	-11.87	0.14	NEP	NEP	NEP	Adulterated	Local	100%
<i>SB-QC2</i>	-11.38	0.44	NEP	NEP	NEP	Adulterated	Local	100%
<i>SB-QC3</i>	-26.33	0.06	-25.90	0.01	0	C4 sugar-free	Imported	0%
<i>SB-QC4</i>	-28.22	0.07	-26.80	0.87	1	C4 sugar-free	Imported	0%
<i>SB-R1</i>	-22.02	0.00	-23.60	0.79	-2	Adulterated	Local	14%
<i>SB-S1</i>	-27.85	0.05	-25.83	0.29	2	C4 sugar-free	Local	0%
<i>SB-S2</i>	-29.22	0.06	-26.92	0.85	2	C4 sugar-free	Local	0%
<i>SB-S3</i>	-29.70	0.07	-26.29	0.32	3	C4 sugar-free	Local	0%
<i>SB-S4</i>	-26.15	0.13	-23.84	0.05	2	C4 sugar-free	Local	0%
<i>SB-S5</i>	-25.96	0.08	-24.51	0.01	1	C4 sugar-free	Local	0%
<i>SB-S6</i>	-26.37	0.09	-23.95	0.45	2	C4 sugar-free	Local	0%
<i>SB-S7</i>	-27.92	0.05	-24.53	0.10	3	C4 sugar-free	Local	0%
<i>SB-T1</i>	-12.87	0.48	NEP	NEP	NEP	Adulterated	Local	100%
<i>SB-Cg1</i>	-12.73	0.03	NEP	NEP	NEP	Adulterated	Local	100%
<i>SB-O9</i>	-26.02	0.19	-24.92	0.22	1	C4 sugar-free	Imported	0%
<i>SB-Q1</i>	-11.70	0.08	NEP	NEP	NEP	Adulterated	Local	100%
<i>SB-Q2</i>	-11.91	0.03	-24.03	0.05	-12	Adulterated	Local	100%
<i>SB-Q3</i>	-11.82	0.08	NEP	NEP	NEP	Adulterated	Local	100%
<i>SB-Co1</i>	-14.97	0.32	-23.30	0.39	-8	Adulterated	Local	76%
<i>SB-ZS1</i>	-14.33	1.06	NEP	NEP	NEP	Adulterated	Local	100%
<i>SB-D1</i>	-13.74	0.09	-23.74	0.31	-10	Adulterated	Local	87%
<i>SB-Bk1</i>	-12.10	0.44	NEP	NEP	NEP	Adulterated	Local	100%
<i>SB-D3</i>	-12.80	0.01	NEP	NEP	NEP	Adulterated	Local	100%
<i>SB-FTR1</i>	-11.68	0.03	NEP	NEP	NEP	Adulterated	Local	100%
<i>SB-FTR2</i>	-12.54	0.17	NEP	NEP	NEP	Adulterated	Local	100%
<i>SB-FTR3</i>	-11.86	0.20	NEP	NEP	NEP	Adulterated	Local	100%
<i>SB-FTR4</i>	-12.61	0.01	-25.89	0.31	-13	Adulterated	Local	98%
<i>SB-FTR5</i>	-12.74	0.06	NEP	NEP	NEP	Adulterated	Local	100%
<i>D-2024-M-1</i>	-12.29	0.01	NEP	NEP	NEP	Adulterated	Local	100%

D-2024-M-2	-29.11	0.04	-26.88	0.01	2	C4 sugar-free	Local	0%
D-2024-M-3	-28.92	0.09	-25.60	0.10	3	C4 sugar-free	Local	0%
D-2024-M-4	-26.76	0.01	-24.73	0.08	2	C4 sugar-free	Local	0%
D-2024-M-5	-29.38	0.15	-26.26	0.08	3	C4 sugar-free	Local	0%
D-2024-M-6	-12.62	0.02	NEP	NEP	NEP	Adulterated	Local	100%
D-2024-M-7	-13.43	0.09	NEP	NEP	NEP	Adulterated	Local	100%
D-2024-M-8	-14.27	0.02	-24.79	0.01	-11	Adulterated	Local	84%
D-2024-M-9	-27.80	0.21	-24.96	0.03	3	C4 sugar-free	Local	0%
D-2024-M-10	-12.54	0.00	NEP	NEP	NEP	Adulterated	Local	100%
D-2024-M-11	-26.03	0.01	-24.61	0.02	1	C4 sugar-free	Local	0%
D-2024-M-12	-25.45	0.16	-24.81	0.06	1	C4 sugar-free	Local	0%
C-2024-M-1	-26.21	0.13	-27.28	0.01	-1	C4 sugar-free	Local	7%
C-2024-M-2	-25.53	0.16	-26.33	0.63	-1	C4 sugar-free	Local	6%
C-2024-M-3	-26.35	0.14	-27.24	0.11	-1	C4 sugar-free	Local	6%
C-2024-M-4	-25.79	0.08	-25.78	0.95	0	C4 sugar-free	Local	0%

*NEP = Negligible extracted protein; *No % apparent C4 sugar content due to C3-like bulk honey

Among local honey products, the 2021 study reported an adulteration rate of 84.4% (76 of 90 samples; combining store- and online-bought samples). By comparison, the present study observed a lower adulteration rate of 67.4% (58 of 86 store-bought samples). Despite this reduction, the extent of adulteration in affected local samples remained severe. Of the 58 adulterated local samples, 55 (94.8%) contained over 75% apparent C4 sugar, and all 45 samples estimated to be completely substituted with C4 adulterants were of local origin. On average, adulterated local samples contained approximately 95% C4-derived sugars, indicating total or near-total substitution rather than minor blending. Additionally, one local sample exhibited a C3-like bulk isotopic signature but yielded no recoverable protein, rendering it non-compliant with standard ISCIRA criterion.

For imported honey, none of the 41 samples analyzed in the 2021 study were classified as adulterated, corresponding to an adulteration rate of 0%. However, in the present study, four out of 16 (25.0%) imported samples were classified as adulterated. Particularly, one imported sample yielded no protein precipitate despite having a C3-like bulk honey isotopic signature, while three failed based on their ISCIRA indices. For the three imported samples with calculable apparent C4 sugar contents, the mean was approximately 12%, which was considerably lower than that observed among the adulterated local samples. This suggests possible low-level addition of C4-derived sweeteners to authentic honey rather than full substitution. Aside from direct addition, supplemental feeding of bee colonies with C4-derived sugar syrups may also contribute to detectable residual C4 sugar signatures in subsequently produced honey, particularly when feeding is conducted at sufficiently high levels (Guler et al., 2014).

Across all market samples, the present study showed 62 adulterated samples out of 102 (60.8%), compared with 76 out of 131 (58.0%) in the 2021 study. Thus, despite the lower adulteration rate observed among locally produced honey in the present study, the overall adulteration rates between the two study periods remained similar. However, as ISCIRA is primarily capable of detecting C4-derived sugars, a possible shift toward C3-derived adulterants such as beet cannot be ruled out and may remain undetected by the method, particularly if such products still satisfy the prescribed authenticity criteria under PNS/BAFS 185:2022.

Implications for implementation of the revised Philippine National Standard for honey

Beyond providing an updated estimate of C4 sugar adulteration in the Philippine honey market, the present results also provide insight into the continuing challenge of translating honey authenticity standards into effective market control. The 2021 study by Lao et al. demonstrated the applicability of the ISCIRA method to Philippine honeys and provided evidence that C4 sugar

adulteration was widespread in the local honey market. These findings contributed to the subsequent revision of the Philippine National Standard for honey, issued as PNS/BAFS 185:2022, which incorporated stable carbon isotope ratio analysis as an official method for assessing honey authenticity.

The findings of this follow-up study may be affected by technical factors such as the sampling location and period. It can also be influenced by policy-related factors, such as that the adoption of a revised standard has not been matched by effective implementation, and by the state of the market itself. Although the apparent adulteration rate observed in locally produced honey in this study is lower than that reported previously, the continued failure of a majority of tested samples shows that adulterated honey remains widely available in the Philippine market. It is recommended to improve or establish sustained enforcement, routine monitoring, testing access, and clear market accountability for non-compliant honey products in support of a scientifically defensible authenticity criterion given by the PNS/BAFS 185:2022.

This implementation gap is especially important because many of the failed samples were not borderline cases. A large fraction of non-compliant samples, mostly locally produced, showed negligible extractable protein and high apparent C4 sugar content, indicating that some products sold as honey may contain little genuine honey material. Such products undermine consumer protection and create an uneven market for legitimate bee farmers, who must compete with cheaper, adulterated products.

A nationwide market monitoring based solely on ISCIRA may be limited by cost, laboratory capacity, technical requirements, and sample throughput. Complementary rapid-screening tools can therefore help expand monitoring coverage by identifying high-risk or suspect samples that should be prioritized for confirmatory testing. In particular, X-ray fluorescence analysis coupled with machine learning offers a promising prescreening approach because it can provide faster, lower-cost, and more portable verification of honey (Bauyon et al., 2023). Such tools should not replace ISCIRA but can support early screening and improve the efficiency of regulatory surveillance.

Overall, the results show that the revision of the Philippine National Standard for honey was a necessary and important step toward science-based regulation. However, the persistence of widespread adulteration demonstrates that standard-setting must be followed by standard implementation. Sustained market surveillance, stronger regulatory enforcement, broader access to authenticity testing, and validated rapid-screening tools are needed to ensure that PNS/BAFS 185:2022 becomes an effective

instrument for protecting Filipino consumers and supporting legitimate bee farmers.

CONCLUSION

This study provides an updated assessment of C4 sugar adulteration in honey products sold in selected Philippine markets, supplementing the initial market assessment conducted in 2021. Using the ISCIRA method, 40 of 102 samples (39.2%) complied with the prescribed authenticity criteria, while 62 of 102 (60.8%) were classified as non-compliant. Among the non-compliant samples, 39 (62.9%) yielded no recoverable protein, while 55 (88.7%) had apparent C4 sugar contents greater than 75%, including 45 samples estimated to be completely substituted with C4-derived sugars. These findings show that severe C4 sugar adulteration remains prevalent among honey products available in the surveyed markets. Among locally produced honey, 58 of 86 samples (67.4%) were non-compliant, while four of 16 imported samples (25.0%) also failed the authenticity criteria. The latter finding contrasts with the 2021 survey, in which none of the 41 imported samples tested were classified as adulterated and indicates that authenticity monitoring should encompass both local and imported products.

Overall, these findings highlight that the formal adoption of PNS/BAFS 185:2022 must be accompanied by active and enforced implementation through sustained market surveillance and regulatory oversight. Regulatory and consumer protection agencies (e.g., the DA, FDA, and DTI) should utilize the revised standard as a technical basis to establish clear compliance mechanisms. These should include routine market testing, enforceable sanctions for non-compliant products, and incentives encouraging producers and retailers to adhere to these standards.

Effective implementation will also require sustained institutional and financial support for regulatory bodies and testing laboratories to establish or expand access to ISCIRA-based confirmatory testing. To complement ISCIRA, future efforts should prioritize the development and validation of rapid, cost-effective screening tools such as handheld X-ray fluorescence (XRF) analysis paired with machine learning models to facilitate early identification of suspect products during routine monitoring. Government units can create a large impact by spearheading activities such as regular inspections in the marketing, production, and composition of honey products (Bose & Padmavati, 2024). These measures are necessary to protect Filipino consumers from fraudulent products, support legitimate bee farmers, promote fair market competition, and strengthen the long-term integrity of the Philippine honey industry.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

CONTRIBUTIONS OF INDIVIDUAL AUTHORS

Joshua Kian G. Balaguer – conceptualization, methodology, formal analysis, investigation, writing - original draft, review & editing, visualization. **Remjohn Aron H. Magtaas** – conceptualization, methodology, formal analysis, investigation, writing - review & editing, visualization. **Andrei Joshua R. Yu** – methodology, investigation, writing - review & editing. **Mary Margareth Bauyon-Isidro** – investigation, writing - review & editing. **Roland V. Rallos** – resources, data curation, supervision. **Norman dS. Mendoza** – resources, data curation, supervision. **Angel T. Bautista VII** – conceptualization, methodology, validation, writing- review & editing, supervision.

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