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Polyphenolic Content and Sensory Characteristics of New Zealand Honey Ice Cream

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Abstract: The natural sweetness, unique flavour, and potential health benefits of honey make it a desirable ingredient for ice cream that can increase its appeal for consumers. The aim of this study was to investigate the polyphenolic content and sensory properties of ice cream made using a variety of New Zealand honey (clover, bush, pōhutukawa, rewarewa, kamahi, and thyme honey). The major polyphenols in honey ice cream were quinic acid, pinocembrin, hydroxybenzoic acid, pinobanksin and chrysin. Thyme and clover honey ice cream had the highest concentration of polyphenols. Ice cream sweetened with sucrose, as well as pōhutukawa, rewarewa and kāmahi honey were the most liked ice cream in terms of overall liking.

Keywords: honey; ice cream; honey ice cream; polyphenols; phenolic acids; flavonoids; antioxidants; NZ native honey; clover honey; bush honey; pōhutukawa honey; rewarewa honey; kamahi honey; thyme honey; sensory; CATA

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1. Introduction

Ice cream is a popular product in the dairy desserts category. The growing awareness of the link between food and health, along with the demand for innovative products, has led to the development of new ice cream formulations with functional benefits for human health (Granato et al., 2018) [1]. Studies have investigated the incorporation of food ingredients like green mate and lemon balm (Gremski et al., 2019) [2], ginger (Zingiber officinale) powder (Gabbi, Bajwa, and Goraya, 2018) [3], dried Besni grape (Kavaz, Yüksel, and Dağdemir, 2016) [4], and curcumin-loaded nanoemulsions (Borrin et al., 2018) [5] into ice cream. These additions have increased the polyphenolic content of ice cream without compromising its sensory appeal. The physicochemical characteristics of ice cream can also be improved by incorporating different hydrocolloids into Acacia honey-based lime ice cream (Rahim and Sarbon, 2019) [6]. Notably, ice creams with xanthan gum and carboxymethyl cellulose showed higher overall acceptability compared to guar gum ice cream. In addition, carboxymethyl cellulose also improved the physicochemical properties of the ice cream.

Honey can be a good natural sweetener and sugar alternative for ice cream due to its distinct flavour and potential health benefits. Honey is rich in various sugars, including glucose, fructose, and sucrose, as well as smaller compounds like maltose, maltotriose, isomaltose, turanose, panose, melibiose, and nigerose (Eteraf-Oskouei and Najafi, 2013) [7]. It also contains some fructo-oligosaccharides and oligosaccharides. The carbohydrate content of honey varies, with sources citing values from 60% to 95%, and water content usually below 18% to prevent fermentation (Hossen et al., 2017) [8] (Gašić, Milojković-Opsenica, and Tešić, 2017) [9]; (Wang, Gheldof, and Engeseth, 2004) [10].

Honey is a good source of various bioactive compounds, especially phenolic compounds like flavonoids and phenolic acids. Flavonoids in honey include apigenin, catechin, galangin, isorhamnetin, myricetin, pinocembrin, rutin, chrysin, genistein, luteolin, pinobanksin, quercetin, and kaempferol (Cianciosi et al., 2018) [11]. In addition, phenolic acids in honey include p-coumaric acid, caffeic acid, cinnamic acid, ferulic acid, protocatechuic acid, syringic acid,2-hydroxycinnamic acid, p-hydroxybenzoic acid, chlorogenic acid, ellagic acid, gallic acid, sinapic acid, and vallinic acid. Flavonoids inhibit the enzymes responsible for superoxide anion production by trapping reactive oxygen species. This prevents peroxidation by reducing alkoxyl and peroxyl radicals, as well as chelating transition metals involved in processes that generate free radicals (Biesaga, 2011) [12].

There have been only few studies on polyphenolic content found in native NZ honey. The polyphenols found in honey are mainly flavonoids, phenolic acids, and phenolic acid derivatives. The most common flavonoids found in mānuka honey are luteolin, pinobanksin, quercetin, kaempferol, pinocembrin, and rutin (Chan et al., 2013) [13]; (Deadman, 2009) [14]; (Weston, Brocklebank, and Lu, 2000) [15]; (Yao et al., 2003) [16]. Phenolic acids in honey include p-coumaric acid, caffeic acid, and chlorogenic acid (Chan et al., 2013) [13]; (Weston, Brocklebank, and Lu, 2000) [15]. Only few studies have investigated polyphenols present in New Zealand honey, with most work carried out on mānuka honey (Chan et al., 2013) [13]; (Deadman, 2009) [14]; (Weston, Brocklebank, and Lu, 2000) [15]; (Weston, Mitchell, and Allen, 1999) [17]; (Yao et al., 2003) [16]. Yao et al. (2003) found that mānuka honey contained a high amount of luteolin, chrysin, gallic acid, quercetin, pinocembrin, and pinobanksin (Chan et al., 2013) [13]; (Yao et al., 2003) [16].

The increasing demand for mānuka honey has led to the devaluation of non-mānuka honey, placing financial pressures on beekeepers and causing them to focus solely on mānuka honey production. By utilising non-mānuka honey, there is an opportunity to diversify the market and create value-added products from other New Zealand native honeys. In this study, six New Zealand non-manuka honey varieties were used to formulate the ice creams. Additionally, incorporating honey in ice cream offers an alternative way to increase the polyphenolic content and enhance flavour, an area of research that has been relatively unexplored. Therefore, this research aims to incorporate New Zealand native honey into ice cream and investigate its impact on polyphenolic content and sensory properties.

2. Materials and Methods

2.1. Honey Samples

Six New Zealand honey samples produced between the year 2018 to 2020, including clover, bush, Pōhutukawa, Rewarewa, Kāmahi, and thyme, were used in this study. While these samples were collected by bees foraging in areas with a high density of plants of the respective floral variety, it cannot be guaranteed that the honey samples are 100% monofloral. The honey samples were defined and classified based on Standard 2.8.2 by the Australia New Zealand Food Standards Code [18]. The honeys were grouped based on the dominant pollen or most common pollen from high density of plants of a particular floral variety. These varieties include clover (*Trifolium repens*), pohutukawa (*Metrosideros excelsa*), kanuka (*Kunzea ericoides*), rewarewa (*Knightia excelsa*), kamahi (*Weinmannia racemosa*), and thyme (*Thymus vulgaris*). The bush honey variety is an eclectic blend of native New Zealand floral honey that captures the essence of a bushwalk in New Zealand.

2.2. Formulation of Honey Ice Cream Samples

Six different honeys were used to formulate honey ice cream (i.e., clover, bush, pōhutukawa, rewarewa, kāmahi, and thyme honey), while a control sample of ice cream was formulated using sugar. The ice creams were produced in two batches in accordance with the method outlined by Goff and Hartel (2013) [19]. Milk, skim milk powder, and cream (Anchor, New Zealand) were added in proportions of 49.2%, 8%, and 32% (w/w), resulting in a total fat content of 14.31% and 6.39% milk solids not fat.

An emulsifier and stabiliser (lecithin and xanthan gum from Lotus (Kadac), Australia) were added at 0.6% and 0.1%, respectively. Vanilla essence (Heilala, Tauranga, New Zealand) was added at 0.1%. All ingredients (except for the honey or sugar) were blended, and the mixture was homogenised until smooth to prepare the ice cream mix. The mixture was then heated to 72 °C for 5 min and quickly cooled to 20 °C before the honey was added, then further homogenised. Cooling the mixture before adding honey was performed at a cooler temperature to prevent unwanted Maillard reactions, caramelisation, changes in antioxidant activities, and loss of honey quality, as described by Antony and Farid (2022) [20]. The ice cream was churned using an ice cream and gelato maker (Cuisinart Model 100BCXA, Cuisinart, Stamford, CT, USA for 20 min until it cooled to −4 °C. The ice cream samples were placed in 20 mL clear plastic containers (30 mL) and stored in the freezer at −20 °C until further analysis was carried out.

2.3. Viscosity

The viscosity of the ice cream mix was measured using a rheometer (Brookfield RST-CC, AMETEK Rheometer, AMETEK Brookfield, Middleboro, MA, USA) fitted with the MBT-25F-0011 cylinder and the CCT-25 S/N 04 00175 spindle (Brookfield RST-CC, AMETEK Rheometer, AMETEK Brookfield, Middleboro, MA, USA), using a shear rate of 0–200 s^{-1} at 4 °C for a 20 mL sample. Viscosity was calculated by dividing shear rate by shear stress. Viscosity analysis was carried out in triplicates.

2.4. LC-MS Analysis of Honey Ice Cream Samples

LC-MS was conducted to determine the polyphenolic content in honey ice cream. A 10 g sample of honey ice cream was defatted three times using 10 mL of hexane. The mixture was then centrifuged at 4000 rpm for 20 min at 4 °C, and the supernatant was discarded each time. Next, the protein was precipitated by adding 12 mL of methanol and vortexing for 15 s. The mixture was stored at −20 °C for one hour and then centrifuged at 3950 rpm for 5 min at 4 °C. The supernatant was then transferred to another falcon tube. Subsequently, 12 mL of a 9:1 ratio mixture of methanol and formic acid was added to the remaining precipitate. The mixture was vortexed for 15 s and stored at −20 °C for another hour. The samples were centrifuged again at 3950 rpm for 5 min at 4 °C, and the resulting supernatant was combined with the previously stored supernatant. The combined supernatants were centrifuged at 4000 rpm for 30 min at 20 °C. Then, 5 mL of the liquid obtained from this process was evaporated under a stream of air to reduce the volume to one-fifth of its original volume. Finally, the concentrate was reconstituted with 3 mL of methanol containing 2% acetic acid.

Phenomenex Strata XA Cartridges (Phenomenex, Auckland, NZ, USA) were used to isolate the polyphenols. The cartridges were conditioned with 3 mL of methanol (Fisher Chemicals, Fair Lawn, NJ, USA) followed by 3 mL of Milli-Q water (pH = 7). The supernatant was then loaded into the cartridge, and 4 mL of Milli-Q water (pH = 7) was added. The phenolic compounds retained in the cartridge were eluted using 5 mL of methanol:formic acid (1:9 v/v) (Fisher Chemicals, Fair Lawn, NJ, USA). The eluate was evaporated under a fume hood using an evaporator. Subsequently, the eluate was dried to approximately 0.75 mL, reconstituted with 2 mL of methanol, and mixed with 2% acetic acid (Fisher Chemicals, Fair Lawn, NJ, USA). Before the LC-MS analysis, all samples were filtered using a 0.22 nm filter (Millipore, Bedford, MA, USA).

Commercial standards of polyphenols (rutin, quercetin, kaempferol, luteolin, gallic acid, benzoic, caffeic, p-coumaric, pinobanksin, chrysin, epicatechin, catechin, apigenin-7-o-glucoside, pinocembrin, hydroxybenzoic acid, homovanillic acid, and quinic acid) acquired from Sigma Aldrich (New South Wales, Australia) were used to determine the concentration of polyphenols present in the honey samples.

LC-MS analysis was conducted using an Agilent 1260 Infinity Quaternary LC System (Agilent, Santa Clara, CA, USA). The system consisted of the following components: 1260 quaternary pump (model number: G1311B), 1260 infinity ALS sampler (model number: G1329B), 1260 infinity TCC column component (model number: G1316A), and the 1260 infinity diode array detector (DAD) (model number: G4212B) that were connected to a 6420 triple quadrupole LC/MS system with electrospray ionisation (ESI) source (model number: G1948B).

The MS ionisation source conditions were as follows: capillary voltage of 4 kV, drying gas temperature of 300 °C, drying gas flow of 10 L/min, and nebulizer pressure of 40 psi. The negative ionisation mode was performed using multiple reaction monitoring (MRM) for quantitative analysis. The MRM transitions with collision energy and cell accelerator voltage are summarised in Table 1, showing the retention times and chemical formulas of the different polyphenolic compounds.

Table 1. Liquid chromatography mass spectrometry MRM transitions.

Compound Name	RT (min)	Molecular Formula	R^2	Precursor Ion	Product Ion	Fragmentor	Collision Energy	Cell Accelerator Voltage	Polarity
Apigenin 7-o-glucoside	20.4671	$C_{21}H_{20}O_{10}$	y = 60.3130x + 697.9966 R^2 = 0.9984	431	431	220	0	7	Negative
				431	268	220	33	7	Negative
Benzoic acid	19.8129	$C_7H_6O_6$	y = 1.4087x − 23.7276 R^2 = 0.9979	121	121	100	0	7	Negative
				121	77	100	8	7	Negative
Caffeic acid	12.6685	$C_9H_8O_4$	y= 33.3529x + 722.820 R^2 = 0.9980	179	135	80	13	7	Negative
				179	134	80	34	7	Negative
Catechin	11.8525	$C_{15}H_{14}O_6$	y = 4.1913x − 21.0171 R^2 = 0.9990	289	245	140	6	7	Negative
				289	203	140	12	7	Negative
Chrysin	26.1441	$C_{15}H_{11}O_4$	y = 8.4415x + 25.9013 R^2 = 0.9997	253	143	160	24	7	Negative
				253	119	160	32	7	Negative
Gallic acid	2.3883	$C_7H_6O_5$	y = 2.7894x − 57.457 R^2 = 0.999	169	169	200	0	7	Negative
				169	128	200	10	7	Negative
				169	79	200	24	7	Negative
Homovanillic acid	13.9163	$C_9H_{10}O_4$	y = 0.9153x + 2.2748 R2 = 0.9986	181	137	80	1	7	Negative
				181	122	80	9	7	Negative
Hydroxybenzoic acid	7.9288	$C_7H_6O_3$	y = 5.1567x + 209.097 R^2 = 0.9968	137	137	80	0	7	Negative
Kaempferol	22.8312	$C_{15}H_{10}O_6$	y = 101.8595x R^2 = 0.9962	285	285	140	0	7	Negative
				285	185	140	23	7	Negative
				285	156	140	26	7	Negative
Luteolin	21.769	$C_{15}H_{10}O_6$	y = 3.844x + 26.456 R^2 = 0.9989	285	133	180	33	7	Negative
p-coumaric acid	17.4594	$C_9H_8O_3$	y = 36.9065x + 251.490 R^2 = 0.9997	163	119	80	12	7	Negative
				163	93	80	36	7	Negative
Pinobanksin	22.9408	$C_{15}H_{13}O_5$ C_{15} $H_{11}O_5$	y = 13.2323x + 203.1724 R^2 = 0.9985	271	253	140	15	7	Negative
				271	197	140	20	7	Negative
Pinocembrin	26.6667	$C_{15}H_{12}O_4$	y = 3.708x − 5.674 R^2 = 0.9992	255	213	140	16	7	Negative
				255	107	140	26	7	Negative
Quercetin	21.8163	$C_{15}H_{10}O_7$	y = 35.3454x R^2 = 0.9968	301	179	140	10	7	Negative
				301	151	140	16	7	Negative
Quinic acid	1.2908	$C_7H_{12}O_6$	y = 17.0651x + 297.7674 R^2 = 0.9978	191	191	160	0	7	Negative
Rutin	19.6387	$C_{27}H_{30}O_{16}$	y = 11.207x + 77.719 R^2 = 0.9992	609	271	240	64	7	Negative
				609	300	240	40	7	Negative

The Agilent Poroshell EC-C18 (2.1 × 150 mm, 2.7 μm) column was used for LC-MS analysis. The mobile phases consisted of water containing 0.1% (*v*/*v*) formic acid (A) and acetonitrile containing 0.1% (*v*/*v*) formic acid (B). The flow rate was 0.30 mL/min, and the column temperature was maintained at 40 °C. The initial gradient condition was 95:5 (A:B) and was held for 5 min. From 5 to 8 min, the proportion of B was increased to 10% and held for 5 min. Subsequently, from 13 to 16 min, the proportion of B was increased to 30%, and from 16 to 18 min, B was increased to 45% and held for 5 min. From 23 to 25 min, the proportion of B was increased to 80% and held for 3 min. Then, from 28 to 29 min, B was decreased to 5%. The total run time was 40 min, and the injection volume was 5 µL.

2.5. Sensory Analysis

Sensory analysis of the ice cream samples was conducted at the Auckland University of Technology sensory laboratory over a span of one week. A total of 54 participants, consisting of 30 females and 24 males, aged between 18 and 65+, took part in the consumer testing. The mean age of the participants ranged between 25 and 34 years old. During the testing, the participants were served all seven ice cream samples along with water to cleanse their palate in between tastings.

The participants were instructed to rate their liking for the products using a 9-point hedonic scale anchored with "dislike extremely" on one end and "like extremely" on the other. They were asked to rate their overall liking as well as their liking of appearance, odour, flavour, taste, and texture. In addition, they were asked to use just about right scales (JAR) ranging from 1 to 5 to indicate their perception of flavour and texture. The JAR scale was anchored with "too much" and "not enough" at each end.

Furthermore, the participants employed the check-all-that-apply (CATA) method, based on the study by Dooley, Lee, and Meullenet (2010) [21], to select sensory attributes that described the ice cream samples. The attributes available for selection included sweet, honey, floral, fruity, herby, medicinal, creamy, vanilla, caramel, and icy.

2.6. Ethics Statement

Ethical approval by the Auckland University of Technology Ethics Committee (AUTEC 17/202) was obtained for this study. Participants were provided with informed consent forms prior to the commencement of the study and were rewarded with supermarket vouchers for their participation in the experiment.

2.7. Data Analysis

All univariate and multivariate analysis were conducted using XLSTAT 2024 (Lumivero, Denver, CO, USA).

2.7.1. Phenolic Data

Analysis of Variance (ANOVA) and Principal Component Analysis (PCA) were both carried out to investigate if there were significant differences in the phenolic content of the honey ice cream and to further visualise the overall differences between the honey ice cream. If significant differences were observed in the ANOVA, Fisher's LSD was then carried out to further investigate the differences between samples.

2.7.2. Consumer Data

ANOVA was utilised to assess if there were significant differences in terms of hedonic scores of the honey ice cream. Tukey's HSD post hoc comparisons were further carried out to determine if any of the attribute reached significant differences. Additionally, Principal Components Analysis (PCA) was carried out to further visualise the overall pattern of consumer liking of honey ice creams in this study.

Consumer CATA data were subjected first subjected to Cochran Q test with multiple pairwise comparisons using the Critical difference (Sheskin) procedure to understand the overall product profile. Additionally, Correspondence Analysis (CA) was conducted to visualise the overall sensory profile of the honey ice cream. In addition, Principal

Coordinate Analysis was carried out to identify the sensory drivers of liking of the honey ice cream samples.

To further gain an understanding of the flavour and texture liking of the honey ice cream samples, the Just About Right (JAR) technique was employed. Penalty Analysis was conducted to further understand whether the intensity of flavour and texture intensity in each honey ice cream sample was perceived as optimal.

3. Results and Discussion

3.1. Polyphenolic Analysis of Honey Ice Creams

The results from one way analysis of variance (ANOVA) of the polyphenol content in the different New Zealand honey ice cream samples are summarised in Table 2. The major polyphenols in the honey ice cream samples were quinic acid, pinocembrin, hydroxybenzoic acid, pinobanksin, and chrysin. These polyphenols, except for hydroxybenzoic acid and quinic acid, were significantly higher in pōhutukawa, kāmahi, and clover honey ice cream samples. Most New Zealand native honeys had high concentrations of pinocembrin and pinobanksin, as reported by Deadman (2009) [14], Weston et al. (2000) [15] and Yao et al. (2003) [16]. This could be because these polyphenols are derived from propolis, as reported by Weston et al. (2000) [15]. Quinic acid was significantly present at high concentrations in rewarewa honey ice cream. Thyme honey ice cream had the highest concentrations of benzoic acid, followed by caffeic acid, luteolin, kaempferol, and quercetin. Pauliuc, Dranca, and Oroian (2020) [22] reported they found a high concentration of hydrobenzoic acid in Romanian thyme honey. Additionally, they reported high concentrations of p-coumaric acid and caffeic acid.

Table 2. Phenolic content present in honey ice cream samples in ng/mL.

Ice Cream Sample	Quinic Acid	Hydroxy-Benzoic Acid	Caffeic Acid	p-Coumaric Acid	Rutin	Benzoic Acid	Luteolin	Quercetin	Kaemp-Ferol	Pinobanksin	Chrysin	Pinocembrin
Clover	3.068^{b}	0.511^{a}	0.038^{ab}	0.081^{a}	0.009^{c}	0.000^{b}	0.033^{bc}	0.000^{b}	0.014^{b}	0.366^{a}	0.105^{a}	0.860^{a}
Kamahi	2.693^{bc}	0.474^{ab}	0.032^{b}	0.024^{c}	0.014^{b}	0.000^{b}	0.024^{c}	0.000^{b}	0.008^{b}	0.175^{b}	0.050^{b}	0.485^{b}
Bush	3.086^{b}	0.396^{abc}	0.033^{b}	0.021^{c}	0.014^{b}	0.000^{b}	0.020^{c}	0.000^{b}	0.011^{b}	0.134^{b}	0.020^{b}	0.173^{c}
Pōhutukawa	3.086^{b}	0.347^{bc}	0.039^{ab}	0.038^{b}	0.009^{c}	0.000^{b}	0.055^{a}	0.000^{b}	0.008^{b}	0.190^{b}	0.032^{b}	0.359^{bc}
Rewarewa	3.541^{a}	0.350^{bc}	0.050^{a}	0.024^{c}	0.010^{c}	0.000^{b}	0.018^{c}	0.000^{b}	0.011^{b}	0.172^{b}	0.026^{b}	0.297^{bc}
Thyme	2.581^{c}	0.334^{c}	0.050^{a}	0.041^{b}	0.017^{a}	0.208^{a}	0.045^{ab}	0.004^{a}	0.029^{a}	0.144^{b}	0.019^{b}	0.211^{c}
F value	6.587	2.692	3.892	32.853	25.703	172.664	6.445	15.958	4.145	13.369	7.127	11.169
p-value	0.004	0.074	0.025	<0.0001	<0.0001	<0.0001	0.004	<0.0001	0.020	0.000	0.003	0.000

[a, b, c]: Means within the column for honey samples with different letters are significantly different ($p < 0.05$) based on Fisher's LSD.

3.2. Principal Components Analysis of the Phenolic Content in the Different Honey Samples

Principal component analysis (PCA) was conducted on the phenolic content data to gain a better understanding of the variations in polyphenols among the different honey ice cream samples. The first two principal components, Factor 1 (F1) and Factor 2 (F2), accounted for 79.97% of the total variance (Figure 1). Thyme honey ice cream exhibited a high positive score along F1, which accounted for 54.76% of the variance and was associated with high loadings of caffeic acid, rutin, quercetin, kaempferol, benzoic acid, luteolin, and coumaric acid. Conversely, pōhutukawa, clover, and kāmahi honey ice cream had high negative scores along F1, which were correlated with high loadings of hydroxybenzoic acid, pinobanksin, pinocembrin, and chrysin. Bush and rewarewa honey ice cream samples demonstrated high positive scores along F2, accounting for 25.21% of the variance and showing a strong correlation with a high loading of quinic acid. These findings align with the ANOVA results summarised in Table 2, which confirmed significantly higher concentrations of quinic acid in both ice cream samples.

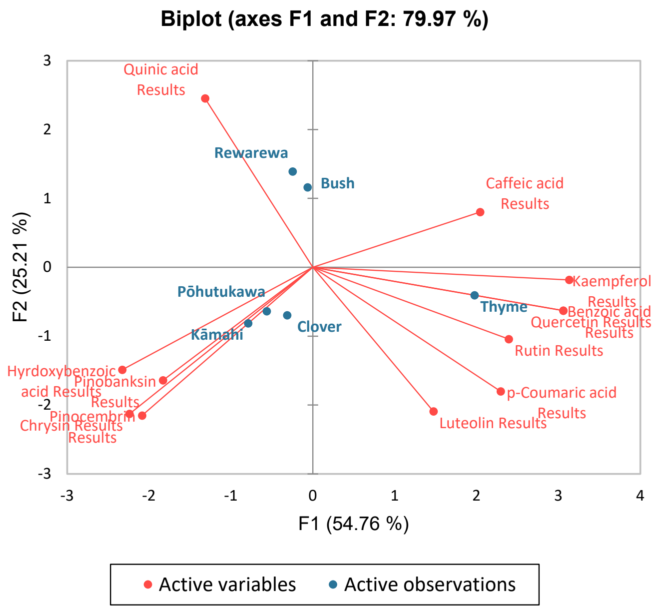

Figure 1. Principal component analysis biplot of the phenolic content in the honey ice cream samples. The active vector variables are the polyphenols compounds, and the observation loadings are the honey samples.

Increased reactive oxygen species (ROS) present in the body causing oxidative stress is one of the major causes of diseases such as diabetes, cancer and myocardial infarction (Sanguigni et al., 2017) [23]. Consuming functional foods rich in antioxidants and polyphenols in our daily diets is now more important than ever. In this study, pōhutukawa, clover, and kāmahi honey ice cream samples were associated with high levels of hydroxybenzoic acid, pinobanksin, pinocembrin, and chrysin. Sanguigni et al. (2017) [23] found that consuming antioxidant-rich ice cream could reduce oxidative stress and improve vascular function in individuals. The authors reported significantly increased serum polyphenol levels and enhanced the ferric reducing ability of the plasma. However, storing the ice cream for long periods of time can diminish the antioxidant capabilities of the polyphenols, making the storing and distribution of such products a bit of a challenge (Vital et al., 2018) [24]. The addition of probiotic bacteria in the ice cream, such as *Lactobacillus* or *Bifidobacterium*, could also increase the functionality of the product, by introducing good bacteria to the gut. Greenbaum and Aryana (2013) [25] found that the honey promoted the growth of the *Lactobacillus acidophilus* in ice cream.

3.3. Consumer Testing of Honey Ice Cream

Consumer testing was conducted to evaluate the acceptability of ice creams formulated using different types of honey. A total of 54 participants (30 females and 24 males) aged between 18 and 65+ took part in the consumer testing, with the mean age of participants falling between 25 and 34 years old.

The results of the one-way ANOVA analysis for overall liking, as well as liking of appearance, aroma, flavour, taste, and texture of the ice cream samples, are presented in Table 3. The ice cream sweetened with sucrose (control) received the highest ratings for overall liking and liking of appearance, aroma, flavour, taste, and texture. However, it is important to note that there were no significant differences in mean liking scores between sucrose and the native New Zealand honey varieties that included pōhutukawa, rewarewa (except for taste), and kāmahi (except for flavour and texture) ice cream samples. On the other hand, the ice cream made with thyme honey had significantly lowest ratings for overall liking and liking of appearance, aroma, flavour, taste, and texture, in comparison to the other ice cream samples such as bush, rewarewa, and kāmahi in this study.

Table 3. Consumer hedonic testing mean scores for the ice cream samples.

Sample	Bush	Rewarewa	Thyme	Sucrose	Kāmahi	Pōhutukawa	Clover	F-Value
Overall Liking	4.75 ± 2.57 [b]	5.52 ± 1.75 [ab]	3.19 ± 2.06 [c]	6.45 ± 1.22 [a]	5.38 ± 1.83 [ab]	5.95 ± 1.51 [a]	4.76 ± 2.12 [b]	16.19 ***
Appearance	5.24 ± 2.18 [bc]	5.59 ± 1.74 [abc]	4.92 ± 1.73 [c]	6.25 ± 1.38 [a]	5.60 ± 1.44 [abc]	5.94 ± 1.34 [ab]	5.53 ± 1.47 [abc]	3.89 **
Odour	4.89 ± 1.51 [ab]	5.00 ± 1.25 [ab]	4.28 ± 2.03 [b]	5.42 ± 1.40 [a]	5.18 ± 1.34 [a]	5.42 ± 1.45 [a]	5.06 ± 1.75 [ab]	3.49 **
Flavour	5.24 ± 2.02 [bc]	5.72 ± 1.57 [abc]	3.28 ± 2.20 [d]	6.48 ± 1.25 [a]	5.31 ± 2.00 [bc]	5.92 ± 1.58 [ab]	4.67 ± 2.28 [c]	16.43 ***
Taste	4.04 ± 1.59 [cd]	4.25 ± 1.38 [bcd]	3.90 ± 1.92 [d]	5.05 ± 1.10 [ab]	4.85 ± 1.42 [abc]	5.33 ± 1.43 [a]	4.94 ± 1.91 [ab]	6.75 ***
Texture	5.74 ± 1.62 [ab]	5.42 ± 1.53 [ab]	4.33 ± 1.93 [c]	6.11 ± 1.57 [a]	5.04 ± 1.85 [bc]	5.77 ± 1.31 [ab]	5.28 ± 1.81 [ab]	6.72 ***

[a, b, c, d]: Means within the column for honey samples with different letters are significantly different ($p < 0.05$ based on Tukey's HSD). The significance levels are denoted as follows: *** for 0.1% significance level, ** for 1% significance level.

There were no significant differences in terms of liking of texture between most of the samples, except for kāmahi and thyme, which had the significantly lowest liking of texture scores. Despite the rheology results in Supplementary Table S1 indicating significantly lower viscosity values for honey ice cream mixtures compared to sucrose-sweetened ice cream, the liking scores for texture of most honey ice creams were not significantly different from ice cream made with sucrose. The liking of texture was only significantly lower for thyme ice cream, which interestingly coincided with its lower viscosity. Ozdemir et al. (2008) [26] reported that sucrose ice cream had a higher viscosity compared to honey and honey/sucrose blend ice cream samples. This could be attributed to the viscosity and water content of honey itself, which was thick. Thyme honey on the other hand was a runnier honey compared to the other honey samples. This can be attributed to its higher water content, which reduced its viscosity.

PCA was then conducted to gain a better understanding of the impact of using honey as a sweetener on the overall liking of the ice cream. The results are depicted in Figure 2, where the first two principal components explained 62.45% of the variance, with Factor 1 (F1) and Factor 2 (F2) accounting for 37.42% and 25.03% of the variance, respectively. The ice cream samples sweetened with pōhutukawa and kāmahi honey, as well as sucrose, received the highest scores along F1, aligning with the high overall liking scores shown in Table 3. Conversely, the ice cream sweetened with thyme honey, which had high negative scores along F1, corresponded to its low overall liking scores as shown in Table 3.

Table 4 shows the overall sensory profile retrieved from consumers using CATA methodology. All attributes reached significance except for mouthcoating. In summary, sucrose showed the least significance compared to other honey samples in terms of floral characteristics. The honey ice cream that was significantly perceived to be possess the most honey attribute was pōhutukawa, followed by kāmahi, clover, and rewarewa. Fruity was least pronounced for the manuka bush and rewarewa samples. Interestingly, thyme honey ice cream showed significantly less creamy, and caramel compared to other samples. Pōhutukawa honey and sucrose ice cream was rated to be significantly the sweetest. Some of the honey samples were rated bitter by consumers, except for the sucrose ice cream. Additionally, vanilla was most pronounced in the sucrose ice cream. Grassy was highest in the thyme honey ice cream and was rated overall relatively low and none in some honey samples. Clover and thyme honey ice cream also showed stronger medicinal profiles. Lastly, thyme honey ice cream was perceived to be significantly the iciest, followed by rewarewa and manuka bush honey ice cream.

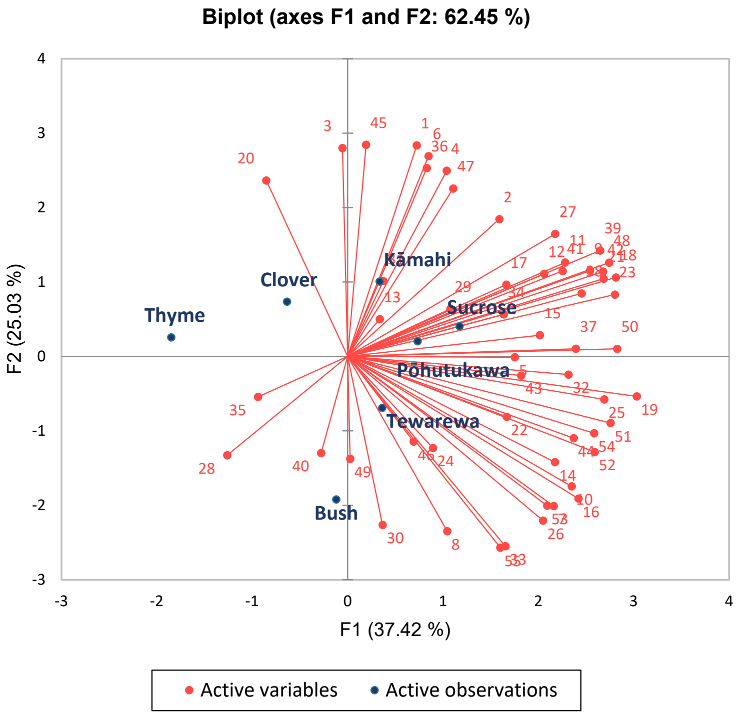

Figure 2. Principal components analysis biplot depicting overall liking of honey ice cream samples with a total of 62.45% of the variances explained by the first two factors. The active vector variables are individual consumer overall liking score, and the observation loadings are the honey samples.

Table 4. Consumer sensory profiles for the ice cream samples. a, b, c: Percentage ratio within the column for honey samples with different letters are significantly different ($p < 0.05$ based on Sheskin procedure).

Attributes	Clover	Kamahi	Manuka Bush	Pohutukawa	Rewarewa	Sucrose	Thyme	*p*-Values
Floral	0.236 (ab)	0.236 (ab)	0.127 (ab)	0.145 (ab)	0.145 (ab)	0.036 (a)	0.273 (b)	0.005
Honey	0.727 (bc)	0.727 (bc)	0.418 (a)	0.745 (c)	0.582 (abc)	0.473 (ab)	0.327 (a)	<0.0001
Fruity	0.164 (ab)	0.182 (b)	0.018 (a)	0.073 (ab)	0.018 (a)	0.055 (ab)	0.055 (ab)	0.002
Creamy	0.400 (ab)	0.564 (bc)	0.691 (c)	0.618 (bc)	0.582 (bc)	0.709 (c)	0.273 (a)	<0.0001
Caramel	0.145 (ab)	0.109 (ab)	0.327 (c)	0.218 (bc)	0.164 (abc)	0.145 (ab)	0.036 (a)	<0.0001
Sweet	0.582 (c)	0.509 (bc)	0.291 (ab)	0.636 (c)	0.436 (bc)	0.600 (c)	0.145 (a)	<0.0001
Bitter	0.182 (b)	0.073 (ab)	0.073 (ab)	0.109 (ab)	0.055 (ab)	0 (a)	0.164 (b)	0.003
Vanilla	0.327 (a)	0.400 (ab)	0.400 (ab)	0.345 (a)	0.382 (a)	0.636 (b)	0.200 (a)	<0.0001
Herby	0.109 (a)	0.073 (a)	0.055 (a)	0.036 (a)	0.018 (a)	0.018 (a)	0.345 (b)	<0.0001
Mouthcoating	0.236 (a)	0.164 (a)	0.218 (a)	0.255 (a)	0.218 (a)	0.164 (a)	0.200 (a)	0.712
Grassy	0.055 (a)	0.055 (a)	0.055 (a)	0 (a)	0.055 (a)	0 (a)	0.255 (b)	<0.0001
Medicinal	0.218 (bc)	0.055 (ab)	0.055 (ab)	0.055 (ab)	0.036 (a)	0 (a)	0.327 (c)	<0.0001
Icy	0.164 (ab)	0.145 (a)	0.218 (ab)	0.127 (a)	0.236 (ab)	0.145 (a)	0.345 (b)	0.008

CATA results are summarised in a correspondence analysis plot, presented in Figure 3, which explained 88.44% of the total variance. F1 and F2 explained 72.27% and 16.18% of the variance, respectively. Sucrose, pōhutukawa, and rewarewa honey ice creams demonstrated negative scores along F1, and were associated with sweet, caramel, vanilla, and creamy attributes, which may explain their high overall liking, and liking of flavour and texture scores as shown in Table 3. Conversely, the thyme honey sample had a high positive score along F1 and was associated with grassy, herby, and medicinal attributes, while the clover honey ice cream had a high negative score along F2 and was associated with the fruity attribute.

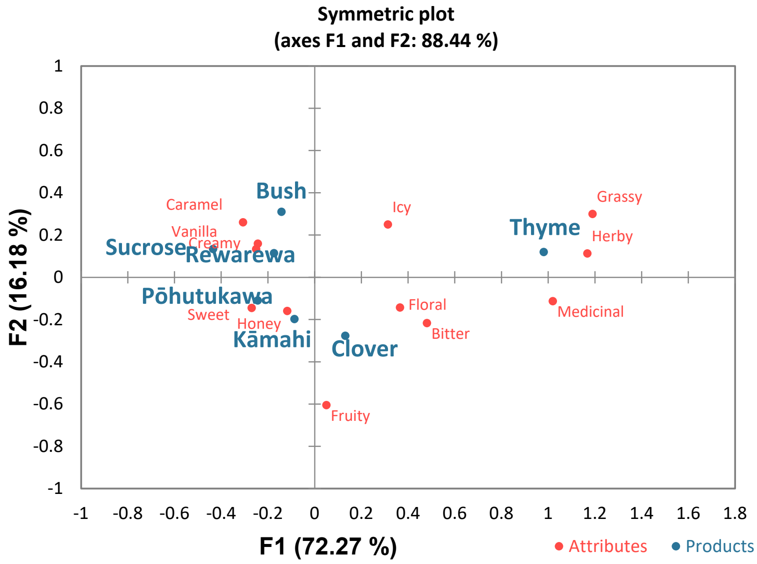

Figure 3. CATA attributes examined in a symmetric CA plot. Symmetric plot of the CATA attributes with a total of 88.94% of the variances explained. The active vector variables are the sensory characteristics, and the observation loadings are the honey samples.

Principal coordinate analysis was conducted to identify sensory attributes that influenced overall liking. The results are summarised in Figure 4, revealing that key drivers of overall liking included sweet, caramel, vanilla, honey, and creamy attributes. Conversely, attributes such as medicinal, icy, bitter, herby, floral, grassy, and fruity had positive loadings and were negatively associated with overall liking. Brun et al. (2020) [27] found that sweetness and odour of a specific honey were the main drivers of liking for honey samples that influenced consumer choice. In another study, Ozdemir et al. (2008) [26] reported that ice creams containing honey had a high overall acceptability and liking of flavour rating compared to ice cream sweetened with sucrose only. However, it is noted that these studies were conducted by trained panels, potentially introducing bias when evaluating consumer acceptance. Rahim and Sarbon (2019) [6] highlighted that the overall acceptance of honey ice cream increased with higher honey concentrations, with a 15% concentration resulting in greater acceptance than a 5% concentration.

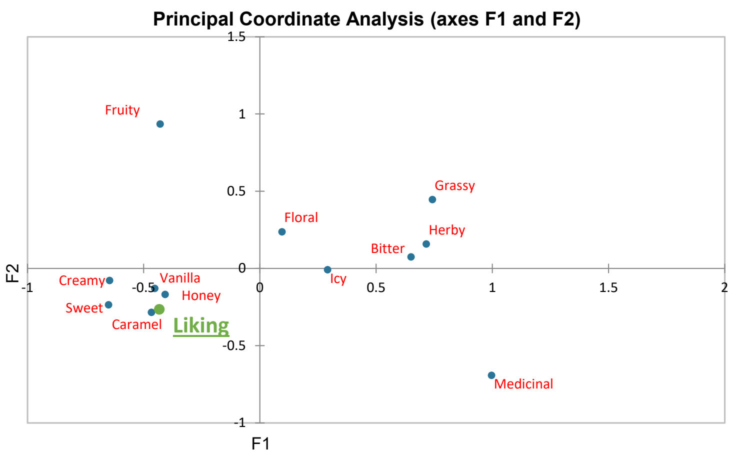

Figure 4. Drivers of liking based on CATA sensory attributes of different ice cream samples using Principal Coordinate Analysis.

Table 5 presents the results of the penalty analysis for the "just about right" (JAR) questions regarding flavour and texture of the samples. The mean drops calculated the difference in liking mean for a specific JAR attribute by eliminating the "too much" or "too little" levels, indicating the points lost when a product contains an excess or insufficient amount of that attribute (Rothman and Parker, 2009) [28]. In terms of texture, consumers did not find it to significantly impact the mean liking score of the sample. Thyme, clover, and kāmahi honey ice cream samples were heavily penalised for having too much flavour, with their mean drops significantly differing from 0. Rewarewa and thyme honey ice cream samples were penalised for not having enough flavour.

Table 5. Penalty analysis conducted with JAR questions on liking of flavour and texture.

Sample	Variable	Level	%	Sum (Overall Liking)	Mean (Overall Liking)	Mean Drops	Penalties	*p*-Value
Bush	Flavour	Too much	18.18%	42.840	4.284	0.732		
		JAR	34.55%	95.310	5.016		0.406	0.582
		Not enough	47.27%	123.120	4.735	0.281		
	Texture	Too much	18.18%	95.400	4.543	0.660		
		JAR	34.55%	109.260	5.203		0.732	0.309
		Not enough	47.27%	56.610	4.355	0.848		
Rewarewa	Flavour	Too much	16.36%	46.440	5.160	1.191		
		JAR	38.18%	133.380	6.351		1.351	0.004 **
		Not enough	45.45%	123.570	4.943	1.409		
	Texture	Too much	29.09%	88.830	5.552	0.067		
		JAR	41.82%	129.240	5.619		0.177	0.715
		Not enough	29.09%	85.320	5.333	0.287		
Thyme	Flavour	Too much	41.82%	67.950	2.954	1.658		
		JAR	14.55%	36.900	4.613		1.662	0.045 *
		Not enough	43.64%	70.740	2.948	1.665		
	Texture	Too much	25.45%	46.890	3.349	0.242		
		JAR	36.36%	71.820	3.591		0.626	0.310
		Not enough	38.18%	56.880	2.709	0.882		
Kāmahi	Flavour	Too much	36.36%	91.080	4.554	1.574		
		JAR	41.82%	140.940	6.128		1.293	0.009 **
		Not enough	21.82%	63.630	5.303	0.825		
	Texture	Too much	23.64%	72.720	5.594	−0.061		
		JAR	49.09%	149.400	5.533		0.310	0.535
		Not enough	27.27%	73.530	4.902	0.631		
Pōhutukawa	Flavour	Too much	30.91%	97.290	5.723	0.335		
		JAR	52.73%	175.680	6.058		0.229	0.579
		Not enough	16.36%	54.270	6.030	0.028		
	Texture	Too much	41.82%	140.130	6.093	−0.010		
		JAR	43.64%	145.980	6.083		0.235	0.570
		Not enough	14.55%	41.130	5.141	0.941		
Clover	Flavour	Too much	54.55%	129.330	4.311	2.158		
		JAR	29.09%	103.500	6.469		2.410	<0.0001 ***
		Not enough	16.36%	28.980	3.220	3.249		
	Texture	Too much	27.27%	86.850	5.790	−0.707		
		JAR	49.09%	137.250	5.083		0.635	0.289
		Not enough	23.64%	37.710	2.901	2.183		

The significance levels are denoted as follows: *** for 0.1% significance level, ** for 1% significance level, and * for 5% significance level.

4. Conclusions

This study investigated the effect of incorporating New Zealand honey in ice cream on the polyphenol content of honey ice cream and its sensory characteristics. PCA results highlighted significant variations in the polyphenol compositions of the various honey ice cream samples. Different types of honey led to distinct polyphenol profiles in the ice cream. The results indicated that the sensory attributes sweet, caramel, vanilla, honey, and creamy were the key drivers of overall liking in the sucrose, rewarewa and pōhutukawa ice cream samples. These attributes were positively associated with higher overall acceptability scores. Interestingly, attributes such as medicinal, icy, bitter, herby, floral, grassy, and fruity had a negative impact on overall liking and were found to be less desirable in the thyme honey ice cream samples. These results suggest that the presence of these sensory attributes, whether through polyphenols or other factors, may influence consumer perception of ice cream. It would be valuable to further investigate the relationship between polyphenol content and specific sensory attributes to better understand the impact of polyphenols on the overall liking of honey ice cream. Overall, this study highlights the importance of considering both polyphenol content and sensory characteristics when developing honey ice cream products. By optimising these factors, manufacturers can create ice creams that are more appealing to consumers, thereby enhancing their marketability and consumer satisfaction.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/app14209260/s1, Table S1. Viscosity data from the honey ice cream mixture. [a, b, c, d]: Means within the column for honey samples with different letters are significantly different ($p < 0.05$ based on Fisher's LSD).

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Informed Consent Statement: Participants were provided with informed consent forms prior to the commencement of the study and were rewarded with supermarket vouchers for their participation in the experiment.

Data Availability Statement: Data is contained within the article and is available upon request.

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