

CHAPTER 4 - RESULTS AND DISCUSSIONS

4.1 Physicochemical Analysis

4.1.1 Moisture Content Analysis

The moisture content of the dried Butterfly Pea Flower samples was determined to standardise the extraction process. The determination of moisture content is important to calculate the exact amount of raw material required to achieve constant solvent to solid ratio. Results are shown in Table 2 for total average moisture content on a wet basis for both Wild Type and Mauve Type.

Table 4.1 Moisture content data for Wild Type and Mauve Type samples.

Sample	Moisture Content Wet Basis (%)
Wild Type	7.87 ± 0.74
Mauve Type	7.76 ± 0.73

The moisture profile for the two phenotypes is almost identical (Table 2) with Wild Type being 7.87% and Mauve Type being 7.76%. The low moisture content (<10%) shows that the flowers were properly dried to prevent enzymatic degradation of the anthocyanins.

4.1.2 Color Intensity

Spectral mapping (wavelength scanning) in the 400–700 nm region showed the visual characteristics of the flower extract variations in a clear and characteristic profile. Figure 4.1 shows the absorbance spectra of five different sample ratios.

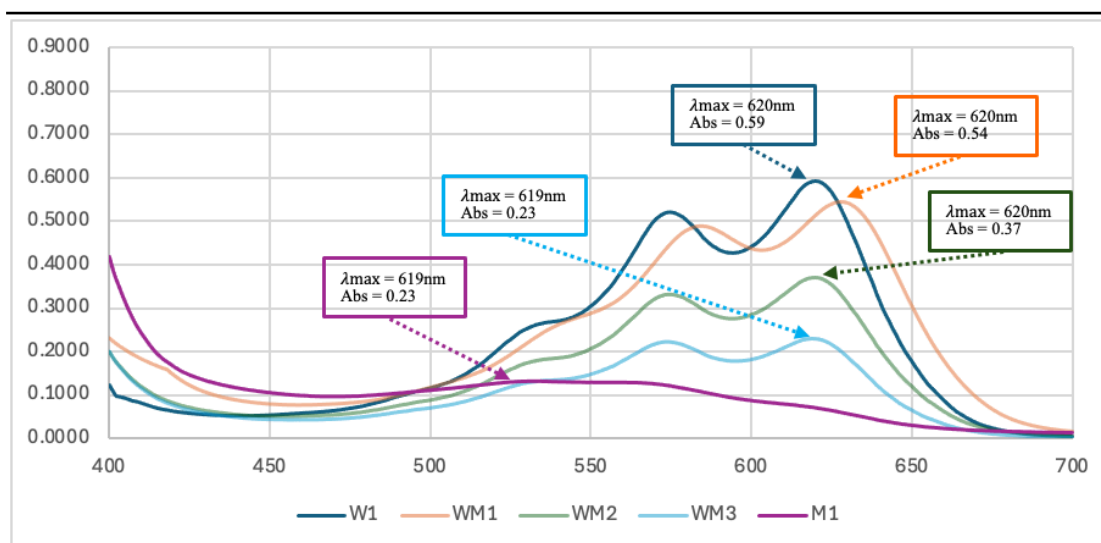


Figure 4.1 UV-Vis Absorbance Spectra of Flower Extracts at Various Ratios (400–700 nm).

Note: Formulation codes are defined as: W1 = 100% Wild Type; WM1 = 75% Wild Type & 25% Mauve Type; WM2 = 50% Wild Type & 50% Mauve Type; WM3 = 25% Wild Type & 75% Mauve Type; M1 = 100% Mauve Type.

Figure 4.1 shows that the W1, WM1, and WM2 had the same maximum absorption wavelength (λ_{max}) at 620 nm. The WM3 sample moved slightly to 619 nm. The spectral shift was drastic in case of 100% mauve variety (M1) as the characteristic peaks in the 620 nm region were flattened out completely and a single distinct peak was observed at 532 nm.

The intensity of color defined as maximum absorbance value at respective λ_{max} was directly proportional to percentage of the Wild variety present in the mixture. Table 4.1. Shows the variations in the order of the intensity of color (descending order of absorbance)

Table 4.2 Maximum absorbance value at the respective λ_{max} of Flower Extracts at Various Ratios (400–700 nm).

Sample Ratio	Abs max	Wavelength
100% Wild Type	0.59	620nm

75% Wild Type & 25% Mauve Type	0.54	620nm
50% Wild Type & 50% Mauve Type	0.37	620nm
25% Wild Type & 75% Mauve Type	0.23	619nm
100% Mauve Type	0.13	532nm

4.1.2.1 Discussion of Color Phenomena and Pigment Behavior

The differences in the shapes of the lines on the graph and the different changes in the peak wavelengths (λ max) are useful chemical markers indicating the different arrangements of the pigments of the two varieties of flowers.

The 100% Wild Type sample has a unique “double peak” shape at 575 nm and 620 nm. This shape is one of the characteristics of ternatins, the natural blue pigments in normal butterfly pea flowers (Terahara et al., 1998). In these pigments the main color centre is naturally stacked and shielded by attached groups of organic acids and sugars. This structural protection gives the pigment network and provides the raw extract with a strong, stable blue color under acidic conditions, in accordance with the findings of Marpaung et al. (2020).

When more Mauve flowers were added to the mixtures (75%, 50% and 25%) the peak wavelength did not slowly slide sideways across the graph (for example it did not slide horizontally from 620 nm to 600 nm and then 580 nm. But instead the curves kept the same “two-horned” shape as the Wild Type. Just the height of the curves got lower and lower.

In simple pigment science a vertical drop in the height of a curve but no horizontal movement of the wavelength position is a simple physical dilution (Boulton, 2001). This means that the combination of the flowers did not give any new intermediate chemical compounds. The blue ternatin pigment of the Wild Type flower absorbs light much more strongly than the Mauve pigment. Therefore, the shape of the blue

pigment dominates the graph until the blue flower is completely removed from the mixture.

However, the 100% Mauve sample showed a distinct single peak at 532 nm. This change corresponds to simple, un-acylated anthocyanins like cyanidin derivatives. These pigments lack the large attached groups that are required to stack and shield themselves. They lack this structural reinforcement, and thus they exhibit a lighter reddish-pink or mauve color at low pH, and a much lower maximum absorption value (0.13) as compared to the stronger Wild Type flower.

4.1.3 Total Anthocyanins

The total monomeric anthocyanin content was quantified across all five formulations to determine how blending the flower varieties changes the baseline pigment concentration. The raw spectral data and computed quantitative yields for each flower blend ratio are displayed in Table 4.3.

Table 4.3: Total Anthocyanin Content (TAC) and Peak Absorption Wavelengths across Sample Formulations.

Sample Code	$\lambda_{\max}$ (nm)	TAC (mg/L)
W1	549	122.14 ± 4.16^a
WM1	525	90.85 ± 1.48^b
WM2	527	88.54 ± 0.95^b
WM3	533	68.86 ± 0.63^c
M1	523	60.83 ± 0.67^d

Note: Values represent the mean $\pm$ standard deviation of triplicates. Different superscript letters (a-d) indicate statistically significant differences determined by Single Factor ANOVA ($p < 0.05$). Formulation codes are defined as: W1 = 100% Wild

Type; WM1 = 75% Wild Type & 25% Mauve Type; WM2 = 50% Wild Type & 50% Mauve Type; WM3 = 25% Wild Type & 75% Mauve Type; M1 = 100% Mauve Type.

From Table 4.3, a distinct shift in the light spectrum could be observed, moving from the longer wavelength of the pure blue Wild Type (549 nm) down to the shorter wavelength of the pure Mauve flower (523 nm). Interestingly, the mixed blends (WM1, WM2, and WM3) do not follow a perfectly straight linear path, showing minor variations in their peak wavelengths between 525 nm and 533 nm as the extracts interact.

This overall shift happens because the underlying color molecules are structurally different. The deep blue color in the Wild Type comes from "ternatins" (Terahara et al., 1998). These are complex pigments wrapped in a protective armor of sugars and plant acids that lock in the deep blue color at higher wavelengths. The Mauve flower lacks this chemical armor. Its pigments are simpler and lighter, which causes them to bounce light at shorter wavelengths, resulting in a lighter, redder color in water (Marpaung, 2024).

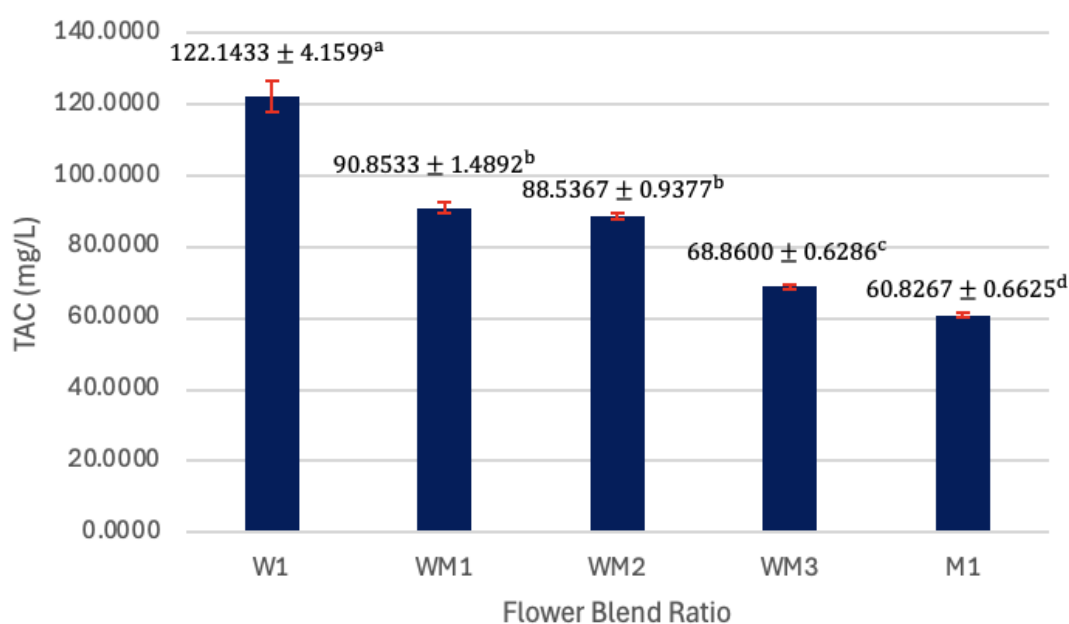


Figure 4.2: Histogram of Total Anthocyanin Content (mg/L) across the five flower formulation ratios.

Figure 4.2.2. Progressive step-wise decrease of anthocyanin density in the five beverage formulations. The data clearly showed a continuous linear decrease in visual pigment concentration as the ratio of the blue Wild Type flower decreases and the Mauve variant increases. This large difference is most apparent when comparing the two pure flowers, the 100% Wild Type (W1) has a high pigment score of 122.14 mg/L, which is twice the concentration of the 100% Mauve Type (M1) at 60.81 mg/L. Statistical testing (ANOVA) showed that the overall difference between formulations was highly significant. Between W1 and the blended ratios, we observe a predictable linear decrease of TAC levels from 75:25 blend (WM1) to 50:50 blend (WM2) to 25:75 blend (WM3). This pattern is consistent with a direct dilution effect, where the total density of the deep blue pigments declines in a steady and predictable fashion in the liquid matrix as the proportion of the lighter Mauve flower increases (Boulton, 2001).

The Mauve flower is genetically deficient in blue pigments due to a specific genetic variation; however, the plant compensates for this loss of pigment by redirecting its internal metabolic building blocks to produce alternative, colourless phenolic compounds instead (Kazuma et al., 2003). This particular biochemical trade-off explains very well the sharp linear fall of the anthocyanin content (TAC) while total phenolic content (TPC) is totally flat, stable and uniform in all five samples.

4.1.4 Total Phenolic Content

The Total Phenolic Content (TPC) of the five flower blends was measured by the Folin-Ciocalteu method. This test essentially determines the total amount of antioxidant compounds in the extracts. The results are calculated and reported directly as milligram Gallic Acid Equivalents per litre (mg GAE/L). The final numbers, standard deviations and statistical groupings for each blend are presented in Table 4.4.

Table 4.4 Total Phenolic Content (TPC) across Sample Formulations

Sample Code	TPC (mg GAE/L)	Relative Standard Deviation (%RSD)
W1	2002.80 ± 22.3944 ^{abc}	1.1182%
WM1	2121.60 ± 92.0091 ^c	4.3368%
WM2	1912.20 ± 93.4645 ^a	4.8878%
WM3	2058.00 ± 65.8747 ^{bc}	3.2009%
M1	1983.00 ± 31.5058 ^{ab}	1.5888%

Note: Values represent the mean concentration ± standard deviation (±SD) of triplicate laboratory measurements. Values within the column sharing common superscript letters (a–c) indicate no statistically significant difference ($p \geq 0.05$) based on Single-Factor ANOVA followed by post-hoc testing. Formulation codes are defined as: W1 = 100% Wild Type; WM1 = 75% Wild Type & 25% Mauve Type; WM2 = 50% Wild Type & 50% Mauve Type; WM3 = 25% Wild Type & 75% Mauve Type; M1 = 100% Mauve Type.

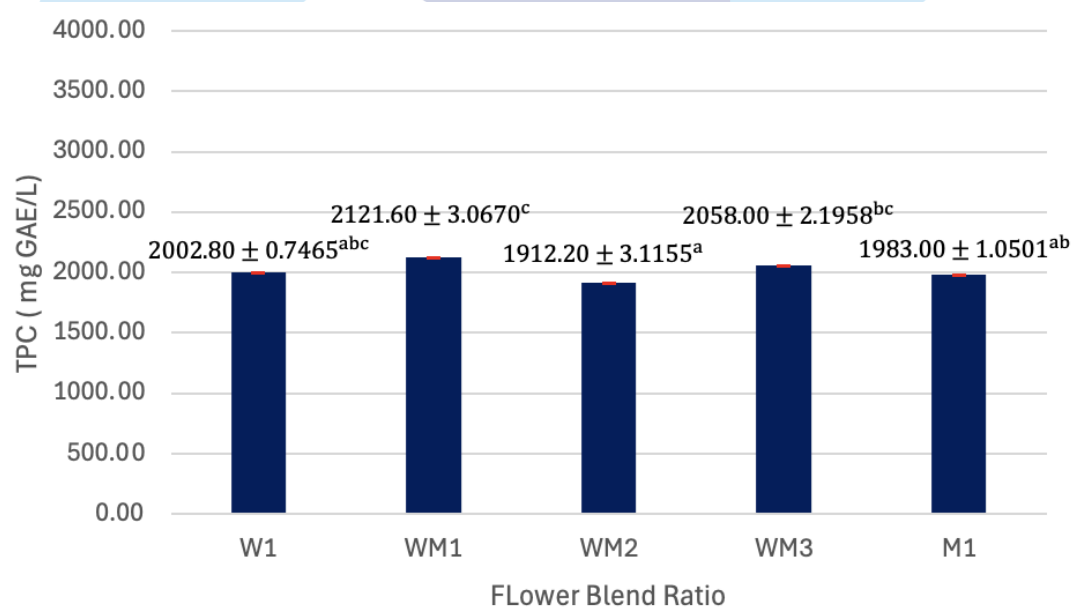


Figure 4.3: Total Phenolic Content (mg GAE/L) of *Clitoria ternatea* and Blend Formulations.

Figure 4.3 Total phenolic content of each beverage sample. Lab data shows that the total amount of phenolic compounds remains flat and highly stable across all formulations, with no significant linear drop or steep variance. Statistical evaluation shows the 100% Wild Type (W1) and 100% Mauve Type (M1) to have nearly equal scores of 2002.80 mg GAE/L and 1983.00 mg GAE/L respectively. The final TPC values were not statistically significantly different between the two pure flowers. The highest concentration was in the 75:25 blend (WM1) at 2121.60 mg GAE/L and the lowest in WM2 extract sample at 1912.20 mg GAE/L. This narrow range indicates a stable baseline with no strong synergistic or antagonistic interactions affecting the overall phenol presence. However, small fluctuations can be observed due to the physical interactions or adhesion of pigments with one another in solution (Marpaung et al., 2019). The overall data set is tightly grouped. Crucially, the %RSD values across the different formulations are all well below 5.0% (with the pure flowers at 1.12% and 1.59% respectively). The very low variance implies that the total phenolic content is statistically uniform and equal across all variations of the sample, confirming a flat and stable bioactive baseline regardless of the blending ratio.

4.1.5. Total antioxidant capacity

The antioxidant of the flower blends was tested using the DPPH radical scavenging assay. This test measures how effectively the active compounds in each sample can take down and neutralize the free radicals. The final results of antioxidant activity are written as a percentage of radical inhibition (% inhibition), where a higher number means stronger antioxidant power. Table 4.5 displays the collected lab data and statistical groupings.

Table 4.5. Antioxidant Radical Scavenging Activity (% Inhibition) across Sample Formulations

Sample Code	DPPH Radical Inhibition (%)

W1	30.79 ± 2.50^a
WM1	21.60 ± 3.89^b
WM2	23.16 ± 4.05^b
WM3	27.85 ± 3.54^{ab}
M1	41.85 ± 2.71^c

Note: Values represent the mean $\pm$ standard deviation of triplicates. Different superscript letters (a-c) within the column denote statistically significant differences determined by Single Factor ANOVA followed by post-hoc testing ($p < 0.05$). Formulation codes are defined as: W1 = 100% Wild Type; WM1 = 75% Wild Type & 25% Mauve Type; WM2 = 50% Wild Type & 50% Mauve Type; WM3 = 25% Wild Type & 75% Mauve Type; M1 = 100% Mauve Type.

As shown in Table 4.5, pure Mauve flower (M1) showed the highest percentage of radical breakdown (41.85%) which was statistically significant from all other groups. The pure blue Wild Type (W1) was in second position with 30.79% inhibition. Interestingly, the intermediate blends (WM1, WM2 and WM3) did not fall in a smooth predictable line, but bounced, with mixing the extracts initially reducing their overall antioxidant efficiency.

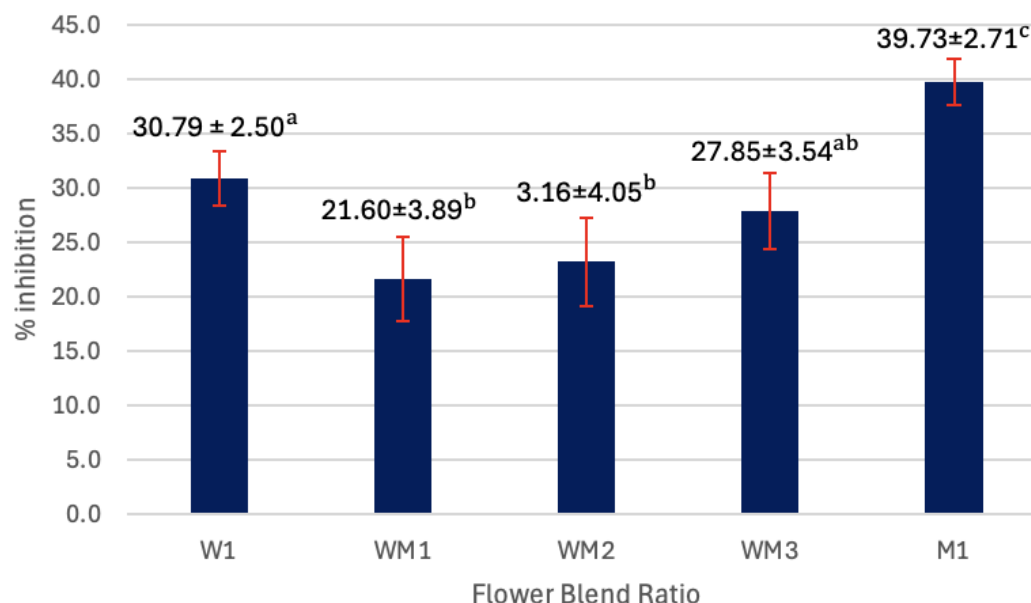


Figure 4.4: Histogram of DPPH Radical Inhibition Percentage across the five flower formulation ratios.

Figure 4.4 shows the free-radical scavenging capacity of the various *Clitoria ternatea* formulations. The data shows that the antioxidant activity is not directly dropping or climbing but is dropping in the middle mixtures and climbing again when the ratio is heavily skewed towards the Mauve flower. Statistical analysis (ANOVA) confirms that these differences are highly significant, with the pure Mauve variant (M1) reaching the highest score of $39.73 \pm 2.71\%$ (letter c), while the pure Wild Type (W1) achieved a baseline score of $30.79 \pm 2.50\%$ (letter a). The 75:25 blend (WM1) and 50:50 blend (WM2) intermediate formulations were the ones that reached the lowest global scores, $21.60 \pm 3.89\%$ and $23.16 \pm 4.05\%$, respectively, and therefore shared the same statistical designation (letter b). However, the latter tendency was successfully reversed by shifting the mixture to the 25:75 ratio in the WM3 blend, where the antioxidant score rebounded significantly to $27.85 \pm 3.54\%$ (letter ab).

This unexpected decrease in the middle blends indicates antagonistic interaction, which is due to mixing the different plant extracts that have different molecular shapes and they physically obstruct each other (Marpaung et al., 2019). In these

intermediate ratios, the large blue pigments (ternatins) of the Wild Type physically crowd the smaller Mauve antioxidants into tight molecular clusters that temporarily lock and hide the active hydroxyl ($-OH$) groups (Vidana Gamage et al., 2021). It is embedded in the clusters and the free radicals of DPPH can not easily approach these active chemical sites and neutralise them during analysis. However, in the optimised WM3 formulation, the huge number of mobile Mauve molecules breaks through this crowding effect and leaves plenty of free and unlinked active hydroxyl sites to fight free radicals quickly.

4.1.6 Correlation between total anthocyanin content and total phenolic content

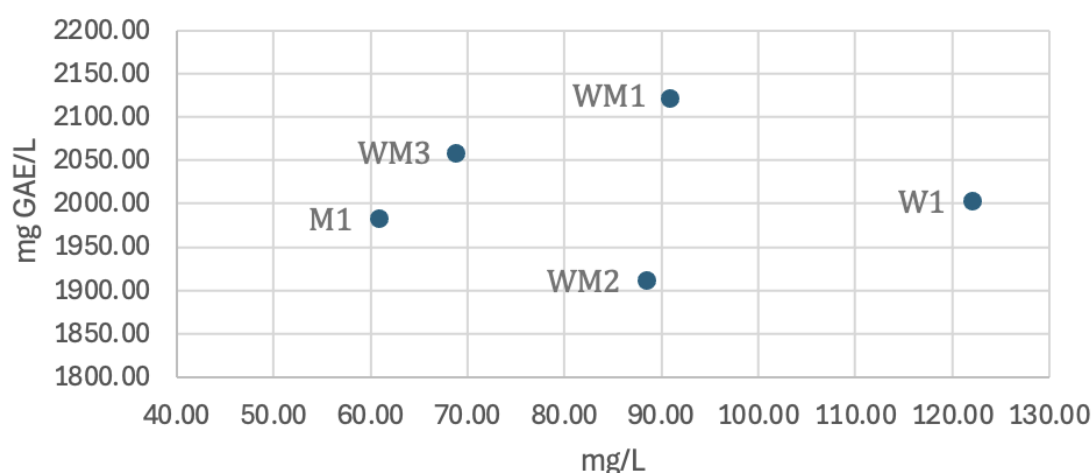


Figure 4.5: Correlation between total anthocyanin content and total phenolic content

Note: W1 = 100% Wild Type; WM1 = 75% Wild Type & 25% Mauve Type; WM2 = 50% Wild Type & 50% Mauve Type; WM3 = 25% Wild Type & 75% Mauve Type; M1 = 100% Mauve Type.

Figure 4.5 shows the relationship of blue colour pigments (TAC) and total healthy compounds (TPC) of the drink. In fact, the graph shows an interesting trend, with the pigments of the blue colour decreasing by about 50.2% between the pure Wild Type (W1) and the pure Mauve variant (M1), but the total phenolic content remains highly stable, between 1900 and 2150 mg GAE/L. This proves that the loss of dark visual colour does not mean the drink loses its health benefits. From a scientific perspective this occurs through the Mauve type flower changing its internal chemistry. It ceases to create heavy blue colour pigments and instead directs its resources to other phenolics

that are colourless (Kazuma et al., 2003). Therefore, the high antioxidant health properties of blended variants such as WM1 and WM3 are fully retained when the drink changes to a lighter purple spectrum.

4.1.7 Correlation between total anthocyanin content and total antioxidant activity

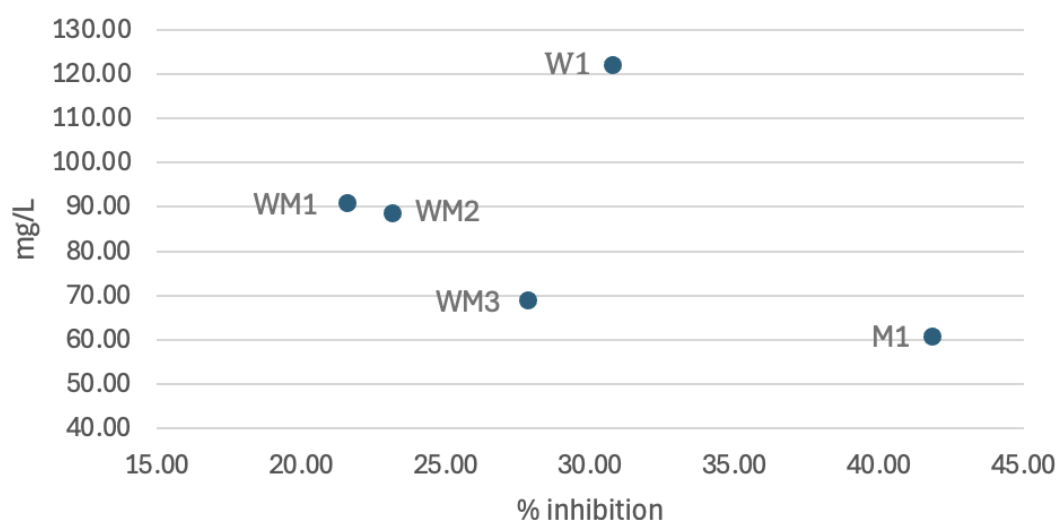


Figure 4.6: Correlation between total anthocyanin content and total antioxidant activity

Note: W1 = 100% Wild Type; WM1 = 75% Wild Type & 25% Mauve Type; WM2 = 50% Wild Type & 50% Mauve Type; WM3 = 25% Wild Type & 75% Mauve Type; M1 = 100% Mauve Type.

The correlation between the blue colour pigments (TAC) and the total antioxidant power (% inhibition) of the beverage is shown in Figure 4.6. The data shows an important scientific finding that the amount of blue colour pigments does not determine the antioxidant strength of the drink, meaning that the DPPH antioxidant activity works independently of the visual colour density (Muzi Marpaung et al., 2017). This is clearly shown by the pure Mauve variant (M1). Despite the fact that M1 contains the lowest amount of blue colour pigments (about 60 mg/L), it has the highest antioxidant activity (41.8487%). This is because the Mauve type flower has a high level of non-anthocyanin flavonols which are very effective for eliminating free radicals, but do not have visible colour (Kazuma et al., 2003). So mixing these variants makes the drink lose the visual blue colour but keeps the great health benefits.

4.1.8 Correlation between total antioxidant activity and total phenolic content

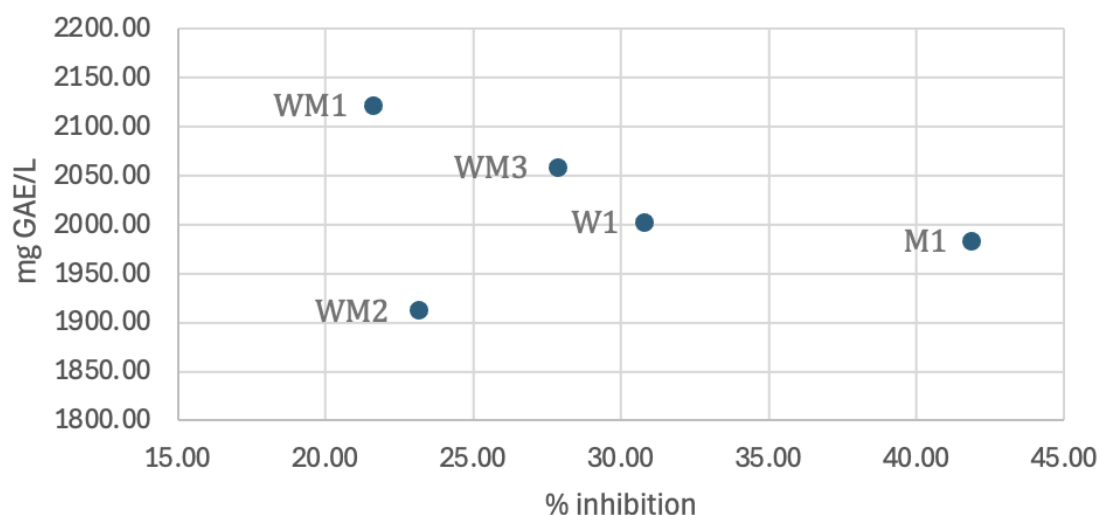


Figure 4.7: Correlation between total antioxidant activity and total phenolic content

Note: W1 = 100% Wild Type; WM1 = 75% Wild Type & 25% Mauve Type; WM2 = 50% Wild Type & 50% Mauve Type; WM3 = 25% Wild Type & 75% Mauve Type; M1 = 100% Mauve Type.

Figure 4.7 shows the correlation between the total antioxidant power (% inhibition) and the total phenolic content (TPC) of the various beverage formulations. The graph depicts a definite biosynthetic trade-off between the flower variants. The total phenolic content is statistically similar and stable among all the samples (between 1900 and 2150 mg GAE/L), however the actual antioxidant power varies enormously (Kazuma et al., 2003). This difference in performance is due to the classes of compounds present. The highest antioxidant capacity is achieved by the pure Mauve variant (M1) with about 42% inhibition. This shows that the colourless flavonols that are abundant in the Mauve type flower are actually better at scavenging free radicals than the deep blue anthocyanins found in the Wild Type. Therefore, the combination of these flowers allows the beverage to present a high level of total healthy phenolics and to modify the formulation for antioxidant performance.

4.2 Focus group discussion (FGD) and product development

4.2.1 Standardization of Beverage Formulations

To link the laboratory chemical data to real consumer preferences, Focus Group Discussion (FGD) are being conducted. This discussion helped assess how to transform the *Clitoria ternatea* (*bunga telang*) extract into an attractive drink that people would want to buy. Laboratory tests show raw flower extracts work well but they have a strong, earthy taste. Blend them with sweet and sour things to mask those raw notes and make the drink taste good.

Five different drink recipes are made to find the best commercial flavour. To ensure the background antioxidant levels and color were identical in all samples, the main ingredients need to be constant: 200 mL of flower extract, 640 mL of water, and a corresponding base of grape jelly (125–150 g) for texture. Then modified the amounts of lychee syrup, mint syrup and lemon juice to create different flavour profiles. Table 4.6 shows the exact ingredient breakdown and initial votes from our 15-person FGD panel.

Table 4.6. Ingredient Composition for the Five Functional Beverage Variants

Components / Ingredients	Variant 1(Standard Balanced)	Variant 2(Sweet Lychee)	Variant 3(Citrus-Mint Punch)	Variant 4(Lychee Mojito)	Variant 5(Light & Vibrant)	Variable Status
Flower extract (mL)	200	200	200	200	200	FIXED
Boiled Water (mL)	640	640	640	640	640	FIXED

Lychee Syrup (mL)	100	115	85	105	90	VARIABLE
Mint Syrup (mL)	20	15	25	25	20	VARIABLE
Lemon Juice (mL)	40	30	50	30	50	VARIABLE
Grape Jelly (g)	125 - 150	125 - 150	125 - 150	125 - 150	125 - 150	FIXED
Total Liquid Volume (mL)	1000	1000	1000	1000	1000	1 L
FGD Panel Preference (n=15)	5 persons	2 persons	2 persons	3 persons	3 persons	-

The recipes are designed to yield a total volume of exactly 1000 mL, to ensure fairness of the testing, as shown in Table 4.6. The panel was able to keep the core flower extract constant and focus only on the effect of changing the syrups and lemon juice to mask the raw flower flavour. The preference row indicates the taste differences among the group. Variant 1 received the highest number of votes.

4.2.2 Qualitative Discussion of FGD Preferences

Focus group discussion feedback suggests that the right balance of sweet, sour, and herbal flavours is critical for a successful drink. Examining the 15 panelists' votes shows us precisely which flavour limitations are preferred by consumers.

4.2.2.1. The Preponderance of the Standard Balanced Profile (Variation 1)

Variant 1 was found to be the most preferred formulation with 5 of the 15 panellists chose variant 1 as their favorite. The panel liked the ratio of the specific 100mL

lychee syrup to 40mL lemon juice. The combination did a good job of masking the natural, green, bean-like flavour of the raw flower extract that is locally called *langu*, without letting the sweet syrup flavour take over the drink. The clean finish really made the whole thing taste a lot fresher. Adding 20 mL of mint syrup gave it a clean finish that made the whole beverage feel much fresher.

4.2.2.2. The Sweet and Sour Extremes (Variations 2 and 3)

Variant 2 and Variant 3 were the least popular with the panel, with only 2 votes each. These two recipes have shown us the limits of consumer dislike. Variant 2 was way too sugary, as it used too much syrup (115 mL), and there was not enough sourness to balance the heavy sweetness, as there was less lemon juice (30 mL). Variant 3, on the other hand, went too far the other way. The large amount of lemon juice (50 mL) and a strong dose of mint (25 mL) gave a sharp, sour and aggressively cold taste that completely obliterated the floral identity of the drink.

4.2.2.3. Medium modifications (Variants 4 and 5)

Variants 4 and 5 received equally and on average 3 votes. Panellists enjoyed the sweet-mint flavour of Variant 4 but did not feel it had the clean crisp finish of Variant 1. Variant 5 was very sharp because of the use of 50 mL of lemon juice, but was much more drinkable than Variant 3, because of the dose of mint of 20 mL, which was less sharp. Overall, both were acceptable, but the panel still found them less balanced than our top recipe, Variant 1.

4.2.3 How Additives Affect Anthocyanin Color Chemistry

Lemon juice changes not only the flavour but also the main reason why the drink changes color, from a food chemistry point of view. The lemon juice has citric acid in it. This changes the pH of the liquid.

Lemon juice is acidic and this acidity alters the physical structure of the color molecules in the flower extract. This changes their normal blue color to a very stable bright reddish pink color (Marpaung et al., 2019; Vidana Gamage et al., 2021). This reaction resulted in the recipes with the most lemon juice such as Variant 3 and

Variant 5 (which used 50 mL) having a clear visual change to a much brighter pink hue. The bright color change had a huge effect on the overall perception of the drink by the panel. The results indicate that product developers can easily manipulate the ratios of these ingredients to control flavour acceptance and visual color appeal in the functional beverage market.

4.3 Sensory evaluation

Sensory evaluation was conducted with 80 untrained consumers using a standard 9-point hedonic liking scale. This test gave us a taste of real consumer preferences for our five flower drink blends. Figure 4.4 shows the visual color shift of the five recipes with changing different flower ratios while the basic drink base remains exactly the same, to help visualise the samples.

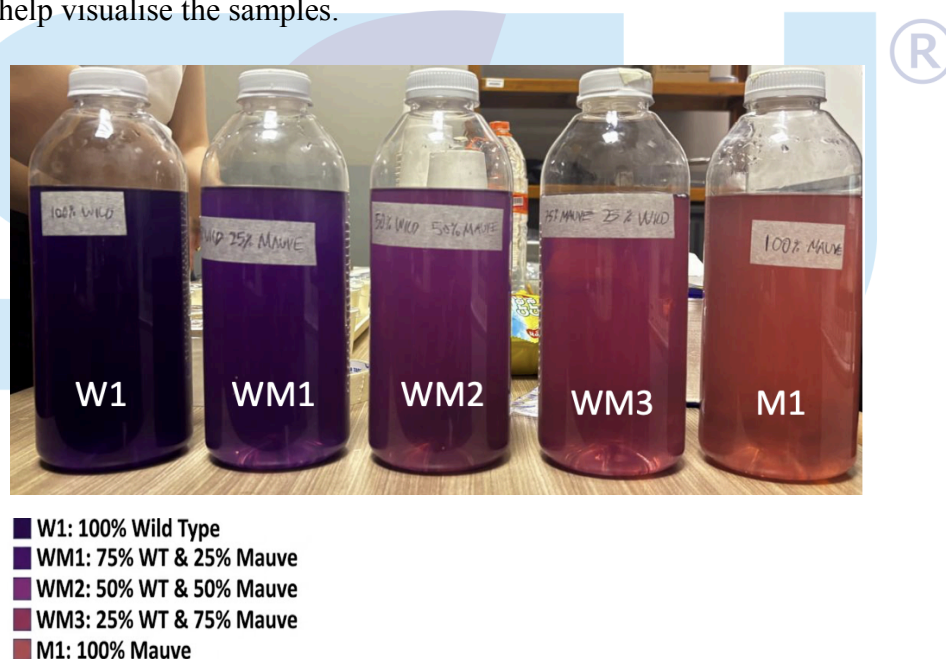


Figure 4.8: Visual profile of the five *Clitoria ternatea* beverage formulation variants ranging from 100% Wild Type (left) to 100% Mauve Type (right).

Figure 4.8 illustrates the natural color shift that happened when blending our extracts. Because these sensory scores are ranking data, we ran a standard Friedman statistical test at a significance level of $\alpha=0.05$ ($df=4$) to look at two main consumer scores: Color Preference Score and Overall Acceptance Score.

A Wilcoxon test was then used to find out exactly which samples got the highest scores and where consumer choices differed. The overall statistical results and the specific letter groupings have been combined in Table 4.7.

Table 4.7. Combined Friedman Test and Wilcoxon Post-Hoc Summary for Consumer Sensory Evaluation (n=80)

Sample Code	Base Code	Color Preference Score (Mean Rank + Wilcoxon Notation)	Overall Acceptance Score (Mean Rank + Wilcoxon Notation)
112	W1	2.8 ^a	2.9 ^a
397	WM1	3.2 ^b	3.2 ^a
478	WM2	2.9 ^{ab}	3.0 ^a
617	WM3	3.3 ^b	3.0 ^a
772	M1	2.8 ^a	3.0 ^a
Test Statistics	Parameter Description	Color Evaluation	Acceptance Evaluation
	Test Statistics (Q)	8.1758	2.2968
	Asymptotic Significance (p-value)	0.0853	0.6813

Note: Sample codes align with the randomized 3-digit blinding keys distributed to the panel. Values within the same column sharing a common superscript letter (a, b) do not differ significantly from one another based on the post-hoc Wilcoxon signed-rank test ($p \geq 0.05$). Base flower formulation percentages are defined as: W1 = 100% Wild Type; WM1 = 75% Wild Type & 25% Mauve Type; WM2 = 50% Wild Type & 50% Mauve Type; WM3 = 25% Wild Type & 75% Mauve Type; M1 = 100% Mauve Type. As shown in Table 4.7, the statistical analysis split our samples into two distinct groups for color preference, while the scores for overall taste and acceptance stayed completely equal across every single recipe.

4.3.1 Analysis of Color Preference Score and Post-Hoc Test

The general test on visual scores gave a value of $Q=8.1758$ with a p-value of 0.0853 . This value is just above the strict cutoff of 0.05 because the visual tastes of our panel of 80 people were different. But when we examined the direct pairs in our follow-up test, we found very clear and specific changes in the colors that consumers preferred.

The drink recipes were divided into two separate tiers of visual preference based on their letters. Sample 112 (W1) and Sample 772 (M1) were statistically grouped under the letter “a” and received the same baseline score of 2.8. So the two extremes of our color spectrum – the traditional pure blue-purple and the innovative pure pink-red – received exactly the same baseline liking from the panel.

Samples 617 (WM3, score 3.3) and 397 (WM1, score 3.2) leaped to a significantly higher preference tier, and both were assigned the letter “b”. The breakthrough shows that consumers clearly prefer the visual depth of the hybrid blended colors to the pure, unmixed flower extracts. In particular, the addition of only a small amount of Wild Type pigment to Sample 617 (WM3) produced a unique color that panellists preferred to the totally pure Mauve alternative (Sample 772) by a wide margin.

4.3.2 Overall Acceptance Score Analysis

The color scores were clearly different visually, but the taste scores were all the same. The analysis of the Overall Acceptance Score yielded a test value of $Q=2.2968$ with a high p-value of 0.6813. This trend was also seen in our pairwise tests, where there was no significant difference between any of the paired samples.

All five recipes are labelled with the same letter “a”, due to this full statistical equivalence. Mathematically this equality proves that the flavour delivery, sweetness and mouthfeel were perfectly consistent from sample to sample. We developed a flavor-masking combination, using lychee syrup, mint syrup and fresh lemon juice, which successfully masked the raw flower’s earthy, bean-like green notes, locally known as *langu*, across the board (Purba, 2020), regardless of which flower cultivar blend was used in the background.

4.3.3 Choosing the Best Recipe

Based on consumer testing and lab results, Sample 617 (Variant WM3) was selected as the final prototype for further testing. The ideal blend of health benefits and customer appeal. First of all, it looks best. It was the most preferred color at 3.3 because when the Wild and Mauve extracts were mixed at a ratio of 25:75, it produced a bright, attractive color that consumers liked much better than the pure flower options. Secondly it bridges the gap between look and nutrition. The small Wild Type base maintains the true color appearance (Vidana Gamage et al., 2021), and the dominant Mauve base increases antioxidant levels, preserving the free radical fighting power at a robust 27.85%. And finally, it tastes good. The earthy, bean-like smell of the raw flower (*langu*) (Purba, 2020) was well masked by the mixture of lychee syrup, mint syrup and lemon juice. The resulting clean, popular flavour profile gave it an overall acceptance rank of 3.0.

4.4 Final Lab Testing of the Approved Drink

The approved drink recipe (Sample 617) by the final consumer, came to the lab in its entirety for analysis named BD (Beverage Drink). We test this sample to see how our healthy flower extract performs in a real drink, with syrups, juice and a grape jelly base. The ultimate laboratory scores for color, phenolics and antioxidant power are summarised in Table 4.8.

Table 4.8 Final Lab Scores for the Finished Beverage (BD)

Parameter Analysis	Observed Value (Mean $\pm$ SD)	Detection Wavelength (λ)	Analytical Metrics
Color Intensity	0.2186 $\pm$ 0.5774	528.33 nm	Absorbance Value (Abs)
Total Anthocyanin Content (TAC)	21.84 $\pm$ 0.6062	524 nm	mg/L
Total Phenolic Content (TPC)	1000.30 $\pm$ 46.7281	765 nm	mg GAE/L
Total Antioxidant	14.0790 $\pm$ 1.7720	517 nm	% DPPH

Activity (TAA)

Inhibition

Note: Data points represent the mean value of triplicate laboratory measurements $\pm$ standard deviation ($\pm$ SD). The Relative Standard Deviation (%RSD) for the TPC analysis was calculated at 4.6714%.

As shown in Table 4.8, turning the raw extract into a commercial drink changed our chemical values, but the final recipe managed to hold onto a very strong antioxidant and color profile.

4.4.1 Analysis of Color Intensity and Total Anthocyanin Content (TAC)

The last beverage had a color intensity value of 0.2186 ± 0.0577 and a total anthocyanin content (TAC) of 21.84 ± 0.61 mg/L. The raw extracts contained less concentration of color pigment, since the addition of water, mint syrup and lychee syrup naturally diluted the mixture. But the color remained surprisingly bright. This is because the citric acid from the lemon juice lowered the pH, which caused the color molecules of the flower to change from a neutral, colorless form to a bright pink form that was very stable (Marpaung, 2020). The natural purple-blue tints of the grape jelly layer added to this pink color perfectly, creating a beautiful multi-layered look that consumers love.

4.4.2 Total Phenolic Content (TPC) Assay

The TPC of the final formulated drink was 1000.30 ± 46.73 mg GAE/L. The high score indicates that our total antioxidant compounds were not significantly reduced after dilution of the flower extract. The other ingredients are directly driving this great retention. In addition, the fresh lemon juice adds unique citrus compounds and vitamin C (Vidana Gamage et al., 2021). The grape jelly gives the large amount of fruit polyphenols remaining from the original grape pulp. These have tested positive and give us a very rich and stable matrix of nutrients. The data are very reliable with a precision score (% RSD) of 4.67% which is safely below the strict 5.0% food science limit.

4.4.3 Total antioxidant activity (TAA) of Final Formulated Drink

The DPPH radical scavenging capacity of the last drink was $14.08\% \pm 1.77\%$. This score is lower than the raw extract mix baseline of 27.85% just due to simple dilution of the active flower parts by water and sweet syrups.

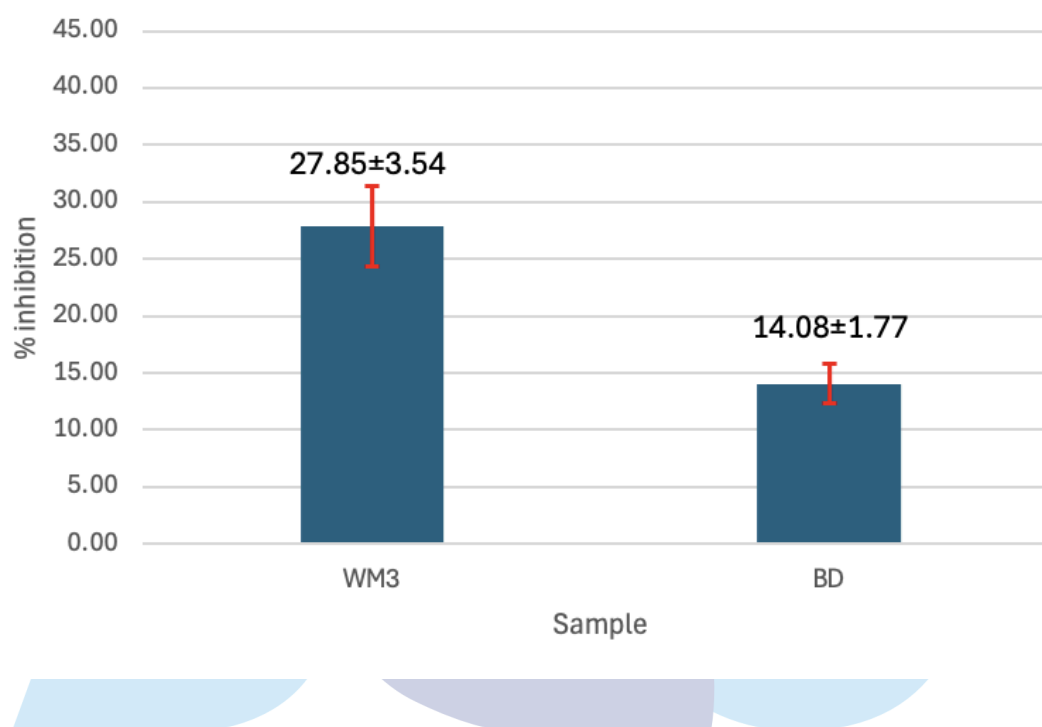


Figure 4.9: Antioxidant Activity Comparison between the Raw Extract Mix and the Finished Beverage Product.

The decrease in radical scavenging capacity due to the steps involved in the preparation of the product is shown in Figure 4.9. Even with this reduction, the final drink has a strong 14.08% anti-oxidant score, showing it still is a very functional health drink. The winning combination is the flower's stable pigments, the vitamin C in the lemon and the thick structure of the jelly. The jelly acts as a physical barrier and encapsulates sensitive antioxidant compounds, preventing oxidation in the presence of air and heat during preparation. "This ensures that the final drink can really deliver real health benefits, along with great consumer flavour, texture and bright color appeal.

4.5 Industrial Relevance, Formulation Parameters, and Commercial Positioning

This research provides the scientific foundation for the combination of *Clitoria ternatea* variants. The practical benefits of the WM3 formula, which combines the flower extract with Ital Lemon juice, sugar-free Tropicana Slim lychee syrup, Ronin mint syrup, and Nutrijell grape jelly, are advantageous for the Ready-To-Drink (RTD) beverage industry. This drink can be mass produced in a food factory using standard liquid processing equipment such as stainless steel mixing tanks, liquid fillers and simple bottling lines without the need for special and costly new machinery.

The industrial formulation can substitute retail liquid juice with lime/lemon powder and essence to obtain realistic shelf life without dependence on highly perishable fresh juice. This modification lets the plant precisely control the drink's pH. The low pH also serves as a natural preservative to inhibit bacterial growth and structurally stabilises the anthocyanin molecules so the beautiful purple colour doesn't degrade over time.

Furthermore, the specific nutritional profile of the final beverage is determined by adding certain commercial ingredients. The approximate total sugar content of the final beverage, calculated based on the percentage volume of each ingredient in the recipe and the specific brand profiles of each ingredient (including the sugar-free Tropicana Slim syrup), is low at approximately 3.45 grams of sugar per 100 mL serving. Although no direct sugar analysis has been performed in the laboratory for this study, this estimated value provides an important baseline for labelling of industrial products. The low sugar level enables the product to be sold as a more healthful low-calorie option, while the combination of Ronin mint syrup and Nutrijell jelly ensures that the sweetness, flavour and mouthfeel texture stay highly appealing and perfectly uniform in every single factory batch.

Considering that this study did not consider a laboratory stability test in real time, specific preservation and packaging technologies are proposed for the final commercialisation. In an industrial process, spoilage microorganisms would be killed off by standard Hot-Filling or In-Bottle Pasteurisation (heating the drink to 85°C - 90°C for 15–30 seconds) before sealing. The factory should also use Opaque or

UV-Blocking Bottles to prevent the light-sensitive flower pigments from fading under retail store lights.

Finally, the beverage is strategically targeted at the medium market segment as an affordable, health-conscious premium product. Finding fresh flowers is very unpredictable due to changing weather and harvest seasons. This study shows that different flower variants can be successfully blended, providing factories with the flexibility to change their raw flower sourcing ratio based on seasonal costs. This flexible flower combined with low-sugar properties, stable commercial syrups and thermal pasteurisation enables companies to reliably produce in bulk a highly attractive, safe, health-oriented and profit-driven functional beverage.

