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Ginger, lemongrass, and stevia tea: antioxidant activity, alpha-glucosidase inhibitory, and sensory quality

[1,*]Puspitojati, E., [2]Waluyo, [1]Rahayu, N.A. and [1]Saputra, H.P.

[1]*Department of Agriculture, Politeknik Pembangunan Pertanian Yogyakarta Magelang, Yogyakarta, 56101, Indonesia*
[2]*Department of Nutrition, Politeknik Kesehatan Yogyakarta, Sleman, 55293, Indonesia*

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Abstract

The incorporation of medicinal plants in the food business is witnessing significant expansion, specifically to fulfil consumer demands for functional foods and beverages. The study developed beverages combining ginger, lemongrass, stevia, and tea. This study aimed to identify the best components for ginger, lemongrass and stevia-infused herbal tea that would demonstrate the highest levels of antioxidants and α-glucosidase inhibition. The optimal ingredients were then evaluated through hedonic testing to evaluate customer satisfaction. The pattern of α-glucosidase inhibition was also examined. The results showed that the herbal tea formulation infused with ginger, lemongrass, and stevia exhibited antioxidant activity and inhibited α-glucosidase activity. Integrating ginger into the formulation could improve antioxidant activity and α-glucosidase inhibition. It can be concluded that the most optimal tea formulation was J3D3, consisting of tea, lemongrass, ginger, and stevia in quantities of 0.4, 0.2, 0.6, and 1.2 g, respectively. The sample had a free radical inhibition activity of 92.68 ppm, categorizing it as a potent antioxidant. Furthermore, the α-glucosidase inhibitory capacity of the best herbal tea was 287.65 ppm. The sensory evaluation formulation had a sensory evaluation of taste, colour, and flavour (specifically in the "like" category). The J3D3 exhibited an uncompetitive inhibition pattern against α-glucosidase, significantly suppressing the enzyme's activity by forming a complex with the substrate enzyme. This finding suggested ginger, lemongrass, and stevia -infused herbal tea could be developed into a commercially available antidiabetic functional beverage due to the in vitro α-glucosidase inhibitory activity.

1. Introduction

Degenerative illnesses, including hypertension, diabetes, and excessive cholesterol, constitute essential global health issues. Knowledge of illness prevention has increased recently, notably in counteracting free radicals that damage the human body. The rapid growth of free radical biology and medicine is due to its profound importance in health, disease, and quality of life. People with diabetes today affect 537 million people between the ages of 20 and 79 years. This number is expected to rise to 643 million by 2030 and 783 million by 2045 (International Diabetes Federation [IDF], 2021). Furthermore, it was estimated that 1.28 billion individuals worldwide have hypertension among the age group of 30-79, with two-thirds of this population residing in countries with low and medium incomes (World Health Organization [WHO], 2023). Hypercholesterolemia remained the most widespread and least vigilantly managed cardiovascular risk factor in 2023 (Banach *et al.*, 2023).

The previous study reported that dietary antioxidants were beneficial in preventing and managing degenerative illnesses (Martemucci *et al.*, 2022). In the context of type 2 diabetes (DM2), managing blood glucose levels during early treatment is crucial. One strategy involves preventing the absorption of carbohydrates after eating, which can be achieved by inhibiting enteric enzymes, such as α-amylase and α-glucosidase, found in the brush borders of the intestine. Today, inhibitors such as acarbose, voglibose, and miglitol are frequently utilized in DM 2 patients. Conversely, the presence of adverse effects associated with synthetic inhibitors, including diarrhoea and abdominal discomfort, has been extensively documented. Nowadays several glucosidase inhibitors have been developed from natural sources,

*Corresponding author.
Email: *endahpuspitojati@gmail.com*

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especially plants (Bindu and Narendhirakannan, 2019).

Medicinal plants have been widely employed for several years due to their remarkable efficacy, few side effects, and low expense in preventing and treating many diseases (You *et al.*, 2022). Some of them have been documented include ginger (Thakor *et al.*, 2023), lemongrass (Nambiar and Matela, 2022), turmeric (Astari, 2020; Salleh *et al.*, 2021), stevia (Kurek and Krejpcio, 2019; Chowdhury *et al.*, 2022), cardamom (Arista *et al.*, 2023), among others.

The use of medicinal plants in the food business is expanding significantly, primarily to satisfy consumer demand for functional foods and beverages. In recent decades, herbal tea has become an increasingly popular beverage choice (Ramphinwa *et al.*, 2023). Many studies have verified that herbal tea is a reliable and safe approach with solid antioxidant activity for preventing and managing DM2 and its associated problems (Kinki, 2020; You *et al.*, 2022; Liu *et al.*, 2023). Herbal tea made from lemongrass has been shown to enhance antioxidant levels in adult women and exhibited potential as a herbal medicine ingredient for diabetic treatment (Tirtaningtyas Gunawan-Puteri *et al.*, 2020; Nambiar and Matela, 2022).

The prior investigation has indicated that the mixture of ginger and tea exhibits a strong antioxidant impact (Makanjuola, 2017). Moreover, herbal tea containing ginger and curcumin showed both antioxidant and antibacterial properties, and it was verified to effectively decrease the transmission of COVID-19 infection (Kusumawati *et al.*, 2021). The prior research also mentioned herbal teas prepared with lemongrass and stevia. The total phenol value and total antioxidant for the blend of 0.37% (w/v) stevia and 0.37% (w/v) black tea was 299.65 and 60.20 mg GAE/L, respectively (Budianta *et al.*, 2020). Another study demonstrated that the ingestion of rosella-stevia tea has an impact on blood glucose levels (Mayasari *et al.*, 2018). Stevia's active components have been shown to have antihyperglycemic and antidiabetic properties in animal models (Chowdhury *et al.*, 2022). This study formulated beverages made from a combination of ginger (*Zingiber officinale*), lemongrass (*Cymbopogon citratus*), stevia (*Stevia rebaudiana*), and tea (*Cammelia sinensis*). Combining ginger and lemongrass was expected to result in a more appealing flavour. In addition, ginger possesses a consumer product value proposition due to its distinctive flavour. Sensory evaluation plays an important part in customer preferences. This review can reduce the possibility of customer dissatisfaction and product recalls. The investigation on antioxidant activity, α-glucosidase inhibitory activity, and sensory quality has not been previously documented. This study aimed to identify the appropriate formula for ginger, lemongrass and stevia-infused herbal tea that exhibits the best antioxidant and α-glucosidase inhibitory properties. The α-glucosidase inhibitory pattern has also been studied. The best formulation was then hedonically tested to investigate the acceptance of consumers.

2. Materials and methods

2.1 Materials

The ginger (*Zingiber officinale*), lemongrass (*Cymbopogon citratus*), stevia (*Stevia rebaudiana*) were acquired from UD Serba Herbal in Boyolali, Central Java, Indonesia. Tea (*Cammelia sinensis*) powder was provided by PT Tambi, Wonosobo City, Central Java. Ethanol 96%, 1,1,diphenyl-2-picrylhydrazyl (DPPH) solution, Na_2CO_3, phosphate buffer (pH 6.8) were purchased from Merck, α-glucosidase and p-nitrophenyl -D-glucopyranoside (pNPG) were purchased from Sigma Aldrich. The other chemicals were of analytical grade. The equipment utilized included an analytical balance (Ohaus, Germany), a cuvette, a UV-Vis spectrophotometer (Dynamica Scientific, Livingston, United Kingdom), an oven (Memmert, Germany) a pH meter (Ohaus, Germany), a water bath (JP Selecta, Spain), and other glassware.

2.2 Preparation of dried ginger, stevia and lemongrass

The ginger rhizomes were thoroughly washed and rinsed. Peeling the ginger skin was accomplished by thinly scraping it, rinsing once, draining the rinse water, slicing the material crosswise and narrowly to a thickness of approximately 0.5 cm, and indirectly sunlight for drying it on a tray created from woven bamboo. The dried ginger was ground using a milling apparatus and filtered through a 60-mesh sieve to produce ginger powder.

The lemongrass stems were separated and cleansed to eliminate any residual dirt adhering to the materials. Subsequently, the two segments of the external epidermis of the stem were removed. Next, the stem was cut into slices with a thickness of roughly 1 cm. These slices were then dried outside on a tray made of woven bamboo. Subsequently, the dried lemongrass was finely ground using a milling machine and filtered through a 60 -mesh screen.

The fresh stevia leaves were exposed to shade drying by spreading them thinly on paper-lined wooden trays and protecting them against direct sunlight to avoid the loss of volatile fragrance components and photo-oxidation. The dried stevia was then pulverized by a milling machine and sieved with a 60-mesh sieve. The

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dried ginger, lemongrass, and stevia powder were then redried in an oven at 60°C for 30 mins. The powdered samples were then vacuum-packed for further use.

2.3 Tea formulation

The study developed a blend of dried herbal tea consisting of tea, lemongrass, ginger, and stevia, referred to as herbal tea. The herbal teas were packaged using tea bags. This study employed a factorial, fully randomized design with fixed variables of 0.4 g of dried tea leaves and 0.2 g of lemongrass. The independent variable in this study was the weight of dried stevia leaves and ginger, as determined using the experimental design. The experimental design generated nine treatments, as shown in Table 1.

Table 1. The experimental design.

Dried ginger (J)/ Stevia leaves (D)	D1 (0.8 g)	D2 (1 g)	D3 (1.2 g)
J1 (0.2 g)	J1D1	J1D2	J1D3
J2 (0.4 g)	J2D1	J2D2	J2D3
J3 (0.6 g)	J3D1	J3D2	J3D3

2.4 Preparation of extract

Dried samples (tea, lemongrass, ginger, stevia powder, and all tea formulation) were macerated using 96% ethanol for 72 hours (dried samples: solvent = 1:5 (w/v)). The crude extracts were purified using vacuum filtering and subsequently concentrated by evaporating them in an oven at a temperature of 65°C. The extracts were subsequently transferred into opaque glass bottled at 4°C and prepared for further analysis.

2.5 α-glucosidase inhibitory capacity assays

The α-glucosidase inhibitory capacity of samples was evaluated by the method of Zhang *et al.* (2022) with slight modifications. 100 µL of extract samples, 100 µL of α-glucosidase solution (1 U/mL), and 200 µL phosphate-buffered saline (PBS, pH 6.8, 0.1 M) were appropriately mixed and then incubated at 38°C for 10 min. 100 mL of pNPG (6 mM) was added to the solution. The mixture was then incubated for 30 mins at the equivalent temperature. Afterwards, the reaction was ended by including 100 µL of Na_2CO_3 (0.1 M). The absorbance was subsequently quantified at 405 nm. Acarbose served as a positive control.

$$\mathrm{IA}\ (\%) = \frac{\mathrm{A1} - \mathrm{A2}}{\mathrm{A1}} \times 100\%$$

Where IA represents the percentage of α-glucosidase inhibitory activity, A1 represents the absorbance when α-glucosidase is present, while A2 represents the absorbance when both α-glucosidase and the sample are present. The IC_{50} value indicated the sample concentration required to inhibit α-glucosidase by 50% under the specified conditions.

2.6 Free radical scavenging inhibition activity assays

The evaluation of the activity of inhibiting free radicals was carried out utilizing the DPPH method (Tristantini *et al.*, 2016). In the test tube, 1 mL of extract sample was added, then 4 mL of 50 µM DPPH solution. The change in hue was then noticed. The mixture was homogenized and incubated for 30 mins in a light-limited environment. The mixture's absorbance was then quantified using a UV-Vis spectrophotometer at 517 nm.

2.8 Evaluation of alpha-glucosidase inhibition pattern

The α-glucosidase inhibition pattern was assessed using the Lineweaver-Burk plot. The experimental condition was identical to the calculation of α-glucosidase inhibitory capacity, followed by the modification of Ghosh and Rangan (2015). The activity of the enzyme was quantified using different levels of concentrations of pNPG (4, 8, and 12 mM) and inhibitor/ sample concentration (0, 0.25, 0.5 mg/mL). The inhibition type was established using the Lineweaver-Burk data to calculate the Michaelis-Menten kinetics constant (Km) The calculation was performed using the regression equation y = a + bx, where x was represented as the reciprocal of substrate concentration [1/S] and y was represented as the reciprocal of velocity [1/V].

2.9 Sensory analysis

Herbal tea in the form of a tea bag was brewed for 4-5 mins in 200 mL water (approximately 80-90°C). The infused tea was subsequently assessed through sensory evaluation utilizing the line scale of the hedonic method. The hedonic LSD (Least Significant Difference) test was employed to assess the panellist's organoleptic perception. This involved distributing the three best characteristic samples of treatment herbal tea. The evaluation criteria comprised colour, flavour, and colour. The analysis involved 100 untrained panellists. The hedonic assessment scores include strongly like (5), like (4), moderate (3), dislike (2), and strongly dislike (1). The study was performed according to the ethics committee approval ref: DP.04.03/e-KEPK.2/090/2024 (Medical and Health Research Ethics Committee, Politeknik Kesehatan Kemenkes Yogyakarta, Ministry of Health, Republic of Indonesia).

2.10 Statistical analysis

The data were subjected to analysis of variance (ANOVA) using a one-way design, followed by a Duncan Multiple Range Test (DMRT) for post-hoc comparisons. The statistical software used for the analysis was SPSS IBM version 25. The hedonic ratings

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were transformed into interval data using the Methods of Successive Interval (MSI) technique before conducting a one-way ANOVA. The significant difference was a confidence interval of 95%.

3. Results and discussion

3.1 Herbal tea ingredients

The ingredients used in herbal tea consist of tea, ginger, lemongrass, and stevia. The proximate contents of herbal tea ingredients are shown in Table 2. Water content is a critical element within the food and beverage sector. The water content of the dried simplicia used as herbal raw materials should be at most 10%. The data collected indicates that dried ginger possesses a greater quantity of water in comparison to stevia, tea, and lemongrass. According to standard practice, Simplisia has a maximal moisture content of 12%. The raw materials used to produce herbal tea qualify as raw materials. Ginger, stevia, and lemongrass exhibited increased ash concentration compared to tea. The ash level of ginger in this investigation was determined to be 8.21% higher than the ash content reported in the previous study, which indicated an ash content of 6.79% for ginger dried at 40°C (Nasution *et al.*, 2023). Lemongrass exhibited the highest fat content, surpassing the earlier study's findings (Shah and Bashir, 2019). This difference can be attributed to variations in the lemongrass cultivars employed in this research. The taste, organic volatiles, and microbiological contamination of food are influenced by its fat content. Table 2 shows that tea had the highest protein content. The presence of 22.86% of crude protein in tea residues has also been reported on a dry-weight basis (Pradhan and Dubey, 2020).

The majority of medicinal plants have been found to possess antioxidant activity. These plants' phenolic compounds and other secondary metabolites contribute to human health by regulating various cellular pathways. The antioxidant activity of herbal tea ingredients is shown in Table 3. Based on the data obtained, the free radical inhibition ability of the four ingredients has significant differences. Lemongrass exhibited the highest percentage of free radical inhibition among other ingredients. IC_{50} of the four ingredients in herbal tea is in the range of 132.49 - 152.96 ppm, included in the medium antioxidant category (Molyneux, 2004). A different investigation revealed that the methanol extract derived from stevia demonstrated antioxidant properties, as evidenced by an IC_{50} value of 24.87±2.18. µg/mL (Lremizi *et al.*, 2023). Moongngarm *et al.* (2022) investigated the antioxidant properties of stevia leaves using a water extraction method aided by ohmic heating. The DPPH test was utilized to compare the data obtained from aqueous and methanolic extracts. Concerning the ohmic treatment, the IC_{50} values varied between 94.68 and 105.19 µg/mL. On the other hand, the corresponding values for the methanolic and aqueous extracts were 118.41 and 241.34 µg/mL, respectively (Moongngarm *et al.*, 2022). The antioxidant activity of 4 plants in Table 3 may be attributed to the abundance of total phenols in these extracts. This finding corresponds to previous research in the discipline, which has consistently demonstrated a positive association relating the concentration of total polyphenols to the antioxidant capacity (Lremizi *et al.,* 2023; Ramphinwa *et al.*, 2023).

Similarly, the α-glucosidase inhibition activity

Table 2. Proximate content of herbal tea ingredients.

Ingredients	Water content (%)	Fat content (%)	Protein content (%)	Ash content (%)	Carbohydrate by diff (%)
Dried ginger	11.74±0.08^{d}	3.09±0.25^{b}	10.68±0.42^{b}	8.21±0.18^{b}	66.29±0.44^{b}
Dried stevia	9.07±0.04^{c}	2.76±0.32^{b}	16.33±0.55^{c}	8.74±0.24^{c}	63.11±0.44^{a}
Tea	6.06±0.04^{a}	0.99±0.06^{a}	21.84±0.10^{d}	5.10±0.08^{a}	66.02±0.21^{b}
Dried lemongrass	6.59±0.04^{b}	5.84±0.54^{c}	6.17±0.00^{a}	8.86±0.18^{c}	72.55±0.32^{c}

Values are presented as mean±SD. Values with different superscripts within the same column are statistically significantly different ($p<0.05$).

Table 3. The antioxidant activity and α-glucosidase inhibitory activity of HT ingredients.

Ingredients	Anti scavenging activity (%)	IC_{50} (ppm)*	α-glucosidase inhibitory activity (%)	IC_{50} (ppm)**
Dried ginger	71.96±0.20^{b}	138.96±0.38^{b}	91.94±0.24^{b}	271.92±0.72^{a}
Dried stevia	65.38±0.86^{a}	152.97±2.00^{c}	92.66±0.50^{b}	269.80±1.47^{a}
Tea	65.95±1.89^{a}	151.72±4.33^{c}	87.48±0.49^{a}	285.79±1.43^{b}
Dried lemongrass	75.48±0.59^{c}	132.49±1.04^{a}	92.40±0.21^{b}	270.55±0.62^{a}

Values are presented as mean±SD. Values with different superscripts within the same column are statistically significantly different ($p<0.05$). IC_{50}*: the sample concentration required for 50% inhibition of free radical under the study conditions, IC_{50}**: the sample concentration required for 50% inhibition of α-glucosidase under the study conditions.

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exhibited notable variations across the four samples. However, no statistically significant changes were seen in the α-glucosidase inhibitory capacity of stevia, ginger, and lemongrass. α-glucosidase inhibitors are highly beneficial as antihyperglycemic drugs due to their ability to block the breakdown of both starch and sucrose. This effectively controls the increase in blood sugar levels after a meal and reduces the impact of food on hyperglycemia. They demonstrated research that the aqueous extract of stevia effectively and proportionally inhibited α-glucosidase, with an IC_{50} value of 596.77 µg/mL (Ruiz-Ruiz *et al.*, 2015). Many studies have shown that the anti-diabetic properties of many plants can be attributed to the existence of flavonoids, alkaloids, phenolic diterpenes, phenolic acids, triterpenoids, steroids, and other nitrogen-containing substances (Lremizi *et al.*, 2023).

3.2 Tea formulation

This study included nine different formulations of herbal tea. Table 4 demonstrates that including ginger enhanced the capacity to inhibit free radicals and α-glucosidase enzymes. However, including stevia leaves in the formulation did not significantly impact antioxidant activity or inhibition of α-glucosidase. The antioxidant activity of all herbal tea formulations surpassed that of the individual component. Incorporating multiple components in the tea formulation decreased IC_{50} to a level below 100 ppm. These findings suggested that combining lemongrass, ginger, tea, and stevia may possess synergistic qualities that enhance their potential for reducing free radicals. The herbal-infused ginger and tea exhibited more significant antioxidant activity than each component's antioxidant activity (Makanjuola, 2017). Molyneux stated that antioxidants with IC_{50} of 50 to 100 ppm were a group of powerful antioxidants (Molyneux, 2004).

Ginger in herbal teas significantly enhanced the inhibitory capacity of α-glucosidase in the formulation. However, in general, it can be observed that there was no increase in α-glucosidase inhibition when the raw materials were turned into tea. The presence of α-glucosidase inhibitors and reduced cytotoxic activity in lemongrass make it a promising candidate for development as a functional component (Santoso *et al.*, 2018). A further study discovered that ingesting ginger extract dissolved in water resulted in enhanced glucose absorption in most tissues among the mice in the experimental groups. Ginger may possess significant potential as an alternative therapy for DM 2 (Pakan *et al.*, 2021). Starch digestion involves the hydrolysis of starch into dextrin and oligosaccharides by α-amylase, followed by the decomposition of these compounds into glucose by α-glucosidase. The glucose was then absorbed and utilized by the small intestine cells. This physiological process increases blood glucose levels after consuming food (Zhang *et al.*, 2022). Prior studies have demonstrated that using rosella-stevia tea could significantly decrease fasting blood glucose levels in women at risk of developing diabetes (Mayasari *et al.*, 2018).

Additionally, this study included an α-glucosidase test comparing the effectiveness of the anti-diabetic commercial drug acarbose. The data revealed that acarbose exhibited a significant inhibitory effect on α-glucosidase, with an IC_{50} value of 51.99 ppm, considerably lower than that of the tested tea formulation. It means that acarbose has a greater capacity to inhibit α-glucosidase activity than HT in this research. Three of the nine formulations were selected based on their superior antioxidant and α-glucosidase inhibitory capacity. According to the available data, J3D1, J3D2, and J3D3 were the most effective formulas. The sensory evaluation was then done on the three most optimal HT formulas.

Table 4. The antioxidant activity and α-glucosidase inhibitory activity of HT formulation.

Formulation	Dried ginger (g)	Dried stevia (g)	Anti scavenging activity (%)	IC_{50} (ppm)*	α-glucosidase inhibitory activity (%)	IC_{50} (ppm)**
J1D1	0.2	0.8	78.97±1.49^{a}	94.97±1.81^{b}	73.95±0.82^{ab}	338.09±3.71^{cd}
J2D1	0.4	0.8	79.21±0.79^{a}	94.69±0.94^{b}	74.45±0.80^{ab}	335.80±3.59^{cd}
J3D1	0.6	0.8	79.88±0.78^{ab}	93.89±0.91^{ab}	88.00±0.18^{e}	284.10±0.58^{a}
J1D2	0.2	1	79.52±0.56^{a}	94.32±0.66^{b}	72.69±3.67^{a}	344.51±7.90^{d}
J2D2	0.4	1	79.56±0.88^{a}	94.27±1.04^{ab}	79.76±1.01^{c}	313.49±3.95^{b}
J3D2	0.6	1	80.09±0.05^{ab}	93.64±0.05^{ab}	85.25±0.76^{d}	293.26±2.63^{a}
J1D3	0.2	1.2	79.19±0.20^{a}	94.71±0.24^{b}	72.01±1.85^{a}	347.34±8.89^{d}
J2D3	0.4	1.2	79.35±0.25^{a}	94.52±0.30^{b}	76.27±0.51^{b}	327.78±2.17^{c}
J3D3	0.6	1.2	80.92±0.09^{b}	92.68±0.10^{a}	86.91±0.26^{de}	287.65±0.56^{a}

Values are presented as mean±SD. Values with different superscripts within the same column are statistically significantly different ($p<0.05$). IC_{50}*: the sample concentration required for 50% inhibition of free radical under the study conditions, IC_{50}**: the sample concentration required for 50% inhibition of α-glucosidase under the study conditions.

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3.3 Sensory quality

A functional beverage must serve two primary purposes of functional food: providing essential nutrients as its primary function and delivering sensory delight as its secondary function. Figure 1 displays the sensory evaluation of three chosen formulations of herbal tea. The formulation differed significantly in taste, colour, flavour, and overall acceptability ($p<0.05$). All samples exhibited a favourable preference as determined by the five-point Hedonic scale. J3D3 exhibited superior sensory quality across all attributes in the "like" category. The abundance of stevia in herbal tea is closely linked to the sweetness level of the product. However, there was a slight presence of bitter aftertaste. Despite this, most participants preferred the J3D3 formulation tea as the best option. In this study, HT has the potential to be commercialized in the market.

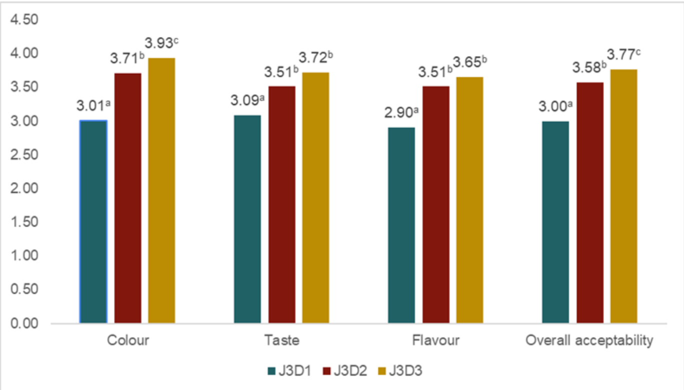

Figure 1. Sensory evaluation of HT. Values with different superscripts within the same parameter are statistically significantly different ($p<0.05$).

3.4 Alpha-glucosidase inhibition pattern

The J3D3 formulation was chosen for the evaluation of its α-glucosidase inhibition pattern. The Lineweaver-Burk plot in Figure 2 illustrates the α-glucosidase pattern of selected herbal tea formulations. It was evident that the herbal teas exhibited a pattern approaching uncompetitive inhibition, as no intersection points were observed on either the x- or y-axis. Following examination of the Lineweaver-Burk plot, it was evident that the inclusion of herbal tea as α-glucosidase inhibitors leads to a decrease in Vmax values from 270.270 to 222.222 µmol/min and Km values from 3.054 to 2.711 (Table 5). The observed decrease in Vmax and Km values suggests that the herbal tea exhibits an uncompetitive inhibitory mechanism. Uncompetitive inhibition occurs when an inhibitor selectively binds to the enzyme-substrate complex (Palmer and Bonner, 2011; Dougall and Unitt, 2015). The binding of the inhibitor resulted in a decrease in the quantity of the ES complex. The reduction in the concentration of the ES complex was caused by the transformation of the ES complex into the ESI complex, which is a distinct complex, upon the binding of the inhibitor to the ES complex. The decrease in the length of the ES complex leads to a longer time for the substrate or product to leave the active site, which ultimately reduces the maximum activity of the enzyme (Vmax). The decline in ES complex can also be ascribed to the drop in Km, which signified the substrate concentration at which the enzyme can operate at half its maximum velocity. It is commonly employed to estimate the enzyme's affinity for a substrate. The inhibitory capacity of some plant essential oils on α-glucosidase has been investigated; the results showed that *Lucidum spore, Aloe ganoderma*, *Fructus cnidii*, and ginger represent uncompetitive inhibition (You *et al.*, 2022).

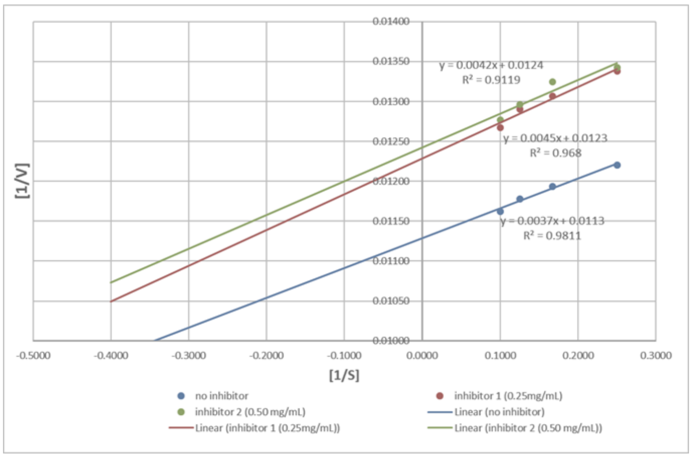

Figure 2. α-Glucosidase inhibition pattern.

Table 5. V_{max}, K_m, and K_i of the HT.

γ Inhibitor (mg/mL)	A	B	V_{max} (µmol/min)	K_m	K_i
0.00	0.0037	0.0113	270.2703	3.0541	-
0.25	0.0122	0.0122	222.2222	-	2.7111
0.50	0.0124	0.0124	238.0952	-	2.9538

V_{max}: the maximum reaction rate of α-glucosidase, K_m: Michaelis-Menten constant, A: represents $1/V_{max}$, B: represents K_m/V_{max}.

4. Conclusion

The comparative investigation revealed ginger, lemongrass, and stevia-infused herbal tea had antioxidant and α-glucosidase inhibitory capacity. The incorporation of ginger into the formulation had the potential to enhance antioxidant capacity and α-glucosidase inhibition. The formulation (J3D3) containing the maximum amount of ginger and stevia, as determined by sensory evaluations, was well accepted regarding taste, colour, and flavour. The herbal teas in this study possessed an uncompetitive inhibition pattern of α-glucosidase, which effectively inhibits the enzyme's activity through a substrate enzyme complex. This finding indicated ginger, lemongrass, and stevia-infused herbal tea could be a commercialized antidiabetic

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functional beverage. Future research is expected to determine the bioavailability of herbal tea during digestion. Furthermore, in vivo testing is required to guarantee the efficacy of herbal tea as a functional drink that promotes health.

Conflict of interest

The authors declare no conflict of interest.

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