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Evaluation of Processing and Storage Techniques for Cat's Whiskers (*Orthosiphon aristatus*) Leaves in Tana Toraja to Improve the Quality and Shelf Life of Herbal Tea Products

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Abstract. The utilization of cat's whiskers (*Orthosiphon aristatus*) as a herbal plant has long been an integral part of the cultural and traditional health practices of the Tana Toraja community. This medicinal plant has been widely used to treat various ailments, particularly urinary tract disorders, and its use has been passed down through generations. However, these traditional practices have not yet been supported by systematic efforts to improve product quality and added value. This study aims (1) to evaluate the effectiveness of different processing techniques for cat's whiskers leaves on the quality of ready-to-brew herbal tea, and (2) to examine the influence of storage techniques on the quality and shelf-life of cat's whiskers herbal tea. A Completely Randomized Design (CRD) was employed, consisting of three processing methods (air-dried sample; blanched and oven-dried at 60°C; and unblanched sample oven-dried at 60°C), two types of packaging (glass jar and standing pouch zipper seal), and two storage conditions (room temperature and cold storage). Observed parameters included moisture content, infusion pH, dried leaf color, and infusion color at weeks two and four. ANOVA results indicated that processing, packaging, and storage had significant effects on moisture content and color ($\alpha < 0.05$), but no significant effect on infusion pH. The treatment involving blanching and oven-drying at 60°C with airtight packaging and cold storage (P2K2S2) produced the best quality, characterized by low moisture content (6.8–8.7%) and the highest color stability. The pH remained stable (6.20–6.92) throughout the storage period. Based on these findings, it is concluded that controlled drying, airtight packaging, and low-temperature storage are the most effective combination of treatments to enhance the quality and shelf-life of cat's whiskers herbal tea.

Keywords: *Orthosiphon aristatus;* Herbal Tea Processing; Storage Stability.

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INTRODUCTION

The utilization of herbal plants in Indonesia has increased significantly over the past few decades. Data from the Ministry of Health indicate that the use of traditional medicines in households rose from 30.1% in 2013 to 44.2% in 2018 (Rahayu et al., 2020). This trend reflects growing public awareness of healthy lifestyles and a shift toward consuming natural products (back to nature). Herbal products such as jamu, capsules, and herbal teas have become increasingly popular in both local and international markets. The main appeal of herbal plants lies not only in their diversity but also in the public perception of their safety, which is believed to have minimal side effects. Previous studies have also shown that communities prefer herbal products due to their accessibility, perceived safety, and lower cost compared to synthetic drugs (Zeng et al., 2020). In line with this trend, the Indonesian govern ment has begun integrating the use of traditional medicinal plants into the formal healthcare system, particularly at the primary care level.

The use of medicinal plants in the Tana Toraja region has long been an integral part of local culture and traditional healing practices. Various herbal plants are used to treat minor ailments such as fever, cough, and urinary tract disorders. Knowledge regarding the use of these plants has been passed down through generations, forming an important ethnobotanical heritage. However, the processing methods commonly practiced by the community remain traditional and are not yet based on scientific approaches. As a result, the quality of the products produced varies, efficiency remains low, and the economic value has not been fully optimized.

Cat's whiskers leaves (*Orthosiphon aristatus*), one of the widely utilized herbal plants among the Toraja community, are known for their pharmacological properties, including diuretic, antihypertensive, and urinary tract–cleansing effects. These leaves contain active compounds such as flavonoids, tannins, saponins, and essential oils, which play essential roles in their pharmacological activities (Faramayuda et al., 2020). Typically, the leaves are simply processed into herbal tea by drying and brewing. Although practical, the lack of standardized processing and storage techniques may reduce product quality. Non-uniform drying processes, inappropriate packaging, and storage in humid conditions may cause changes in leaf color, increased moisture content, and reduced levels of bioactive compounds. Consequently, the resulting herbal tea has lower quality and shorter shelf life and may be susceptible to contamination by molds or other microorganisms (Gamage et al., 2021).

Common issues in the processing of cat's whiskers leaves include uneven drying, non-standard packaging, and suboptimal storage conditions. These factors may decrease product quality in terms of bioactive content, color, aroma, and durability (Lee et al., 2022). Furthermore, if stored in open or humid containers, the product is at risk of contamination by molds and other microorganisms. In response to these challenges, innovations in hygienic and standardized post-harvest processing are needed to produce ready-to-brew cat's whiskers herbal tea that is more practical, visually appealing, and long lasting (Gadde et al., 2021; Nguyen & Nguyen, 2023).

Evaluation of various processing and storage techniques is required to determine the most effective method for preserving active compounds, maintaining organoleptic quality, and extending product shelf life. Inappropriate handling, such as inadequate drying and storage in unsuitable containers, may reduce product quality, decrease active compound content, and cause unpleasant odors as well as mold contamination. Additionally, changes in color, moisture content, and pH may occur during storage. Therefore, scientific evaluation of processing and storage techniques capable of maintaining or improving the quality and shelf life of cat's whiskers herbal tea is necessary. The treatments examined in this study include three processing methods, two storage conditions, and two types of packaging, with a total of 12 samples. The parameters observed include dried leaf color, infusion color, moisture content, and infusion pH during two- and four-week storage periods. The findings are expected to identify the best combination of treatments that can improve the quality and extend the shelf life of *Orthosiphon aristatus* herbal tea.

MATERIALS AND METHODS

This research was conducted from October to November 2025. The collection of raw materials in the form of cat's whiskers leaves and their processing into herbal tea were carried out at the Agricultural Laboratory of the Toraja Christian University of Indonesia. The quality assessment of the herbal tea products was performed at the Laboratory of Analytical Chemistry and Food Quality Control, Department of Food Science and Technology, Faculty of Agricultural Technology, Hasanuddin University. Various instruments were used in this study, including a digital scale, sterile knives and scissors, stainless steel trays, a drying oven, a blender, a desiccator, glass jars, a colorimeter or spectrophotometer, and a moisture analyzer for water content determination. The main material consisted of cat's whiskers leaves (*Orthosiphon aristatus*) obtained from community farmland in Tana Toraja. Additional materials included gauze or filters, aluminum foil, standing pouches with zipper seals, and clean water for washing and blanching.

The research employed a Completely Randomized Design (CRD) with three main factors: processing technique, packaging type, and storage condition. The processing factor consisted of three methods: no blanching with shade drying, blanching followed by drying at 60°C in an oven, and no blanching with oven drying at 60°C. The packaging types used were glass jars and zipper-sealed standing pouches, while the storage conditions included room temperature (±25°C) and cold temperature (±4°C).

The research stages began with raw material preparation, in which healthy, undamaged leaves were selected, cleaned, weighed, washed twice, and drained. Processing was then carried out based on each treatment. In the shade-drying treatment, leaves were dried at an ambient temperature of 28–35°C for 2–5 days until their moisture content reached ≤10%. In the blanching treatment, the leaves were immersed in hot water at 90–95°C for 60 seconds, cooled in cold water for 15 seconds, drained, and dried in a convection oven at

60°C for 6–12 hours until reaching 8–10% moisture content. In the non-blanching oven-drying treatment, the leaves were directly dried in a convection oven at 60°C for 8–16 hours, depending on material thickness, until the moisture content reached ≤10%, with periodic turning of samples to ensure uniform drying. The dried samples were then cooled, weighed (50 g each), packaged according to the assigned treatments using glass jars or zipper-sealed standing pouches, labeled with treatment codes, and stored under two temperature conditions: room temperature and cold temperature.

Quality evaluation was conducted in the second and fourth weeks of storage. The observed parameters included the color of dried leaves measured using a colorimeter or spectrophotometer, infusion color based on absorbance values, final moisture content measured with a moisture analyzer, and infusion pH measured using a pH meter. All data obtained were analyzed using Analysis of Variance (ANOVA). When significant differences were detected among treatments, the analysis was continued with Duncan's Multiple Range Test (DMRT) at a significance level of $\alpha = 0.05$ to determine which treatments differed significantly.

RESULTS AND DISCUSSION

Moisture Content and pH of Cat's Whiskers Herbal Tea

The results of moisture content and infusion pH analysis of cat's whiskers herbal tea at the second and fourth weeks showed noticeable variation among treatments (Figure 1). Overall, the moisture content of the dried cat's whiskers leaves ranged from 6.8% to 11.7%, while the pH values of the tea infusions ranged from 6.20 to 6.92. Based on these ranges, all samples met the quality standard for dried simplicia moisture content (<12%) as defined by national standards, indicating that the samples were suitable to be categorized as ready-to-brew dried herbal material.

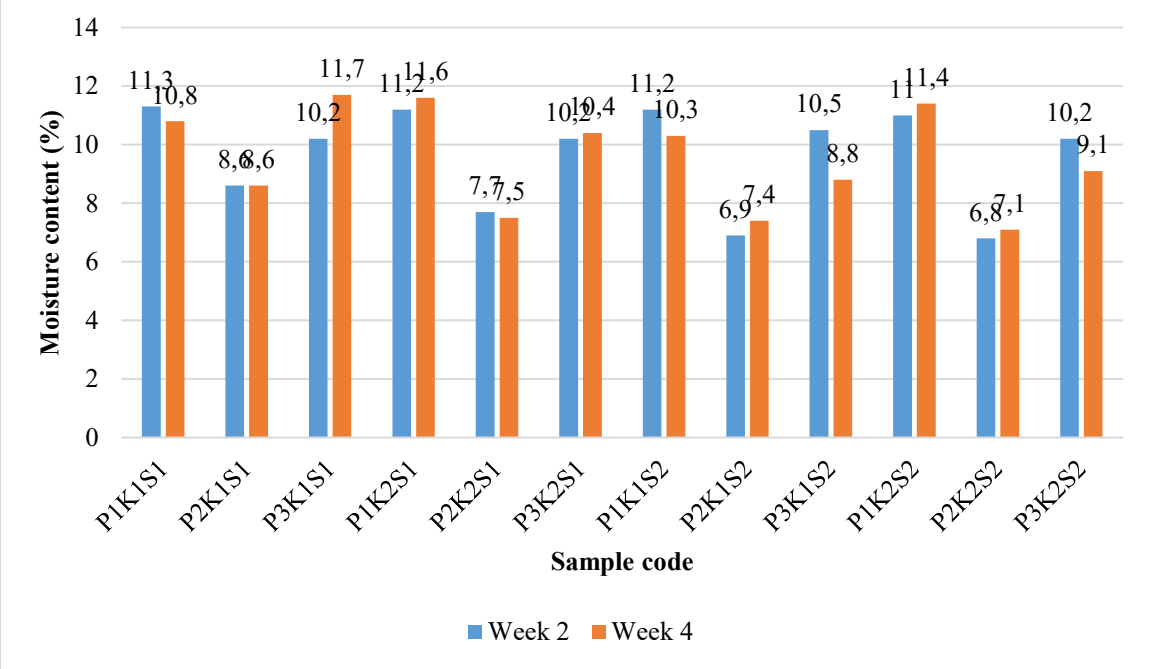

Figure 1. Comparing moisture content of cat's whiskers herbal tea

Figure 1 shows the changes in moisture content of cat's whiskers herbal tea at the second and fourth weeks of storage with different processing, packaging, and storage treatments. The moisture content of all treatments remained below twelve percent, so the product was still within the limit that is considered safe and stable for dried herbal tea. The variations seen between treatments are in line with the results of the statistical analysis that showed processing, packaging, and storage duration caused significant differences in moisture content. Samples that were dried in an oven after being blanched such as P2K2S2 and P2K1S2 generally had lower moisture values at both observation periods. This condition indicates that blanching followed by drying with controlled warm air helps to remove water more effectively and keeps the product more stable during storage. Meanwhile, samples that were dried under shade conditions such as P1K1S1 and P1K2S1 tended to have higher moisture levels because drying that depends on natural air is slower and less consistent.

The shift in values between week two and week four also shows that moisture can move or change during storage. Several samples that were stored at room temperature in standing pouches such as P1K1S1 and P3K1S1 experienced an increase in moisture content which suggests that the packaging material may allow surrounding humidity to enter more easily. On the other hand, samples stored in glass jars especially those placed in cold storage showed more stable moisture conditions because the container is more airtight. These results confirm that the factor with the strongest effect on final moisture content is the processing method followed by packaging type while storage temperature has a smaller but still significant influence. The most stable moisture values were found in treatments that combined blanching and oven drying with glass jar packaging in cold storage which supports better product quality during the storage period.

Table 1. Moisture Content of Cat's Whiskers Herbal Tea in the Second Week

Sample code	Parameter	
	Infusion pH	Moisture content Moisture Analyzer (%)
P1K1S1	6,46	11,3
P2K1S1	6,45	8,6
P3K1S1	6,91	10,2
P1K2S1	6,77	11,2
P2K2S1	6,51	7,7
P3K2S1	6,92	10,2
P1K1S2	6,20	11,2
P2K1S2	6,58	6,9
P3K1S2	6,81	10,5
P1K2S2	6,31	11,0
P2K2S2	6,26	6,8
P3K2S2	6,80	10,2

In all Tables and Figures, the samples are identified using a combined treatment code such as P1K1S1 to represent the specific conditions applied in the experiment. This code consists of three elements: P denotes the processing technique, K refers to the packaging type, and S indicates the storage condition. The numerical values following each letter correspond to different levels within each factor. Specifically, P1 refers to a non-blanching treatment followed by shade drying, P2 represents blanching followed by oven drying at 60°C, and P3 indicates oven drying at 60°C without blanching. The code K1 designates the use of glass jar packaging, whereas K2 indicates zipper standing pouch packaging. Additionally, S1 refers to storage at ambient temperature (±25°C), while S2 represents cold storage (±4°C). Therefore, a sample labeled P1K1S1 corresponds to leaves processed without blanching and shade dried, packaged in a glass jar, and stored at ambient temperature. The use of this coding system ensures a clear, systematic, and organized presentation of the treatment combinations evaluated in this study.

Table 2. Moisture Content of Cat's Whiskers Herbal Tea in the Fourth Week

No	Sample code	Parameter	
		Infusion pH	Moisture content Moisture Analyzer (%)
1	P1K1S1	6,46	10,8
2	P2K1S1	6,45	8,6
3	P3K1S1	6,91	11,7
4	P1K2S1	6,77	11,6
5	P2K2S1	6,51	7,5
6	P3K2S1	6,92	10,4
7	P1K1S2	6,20	10,3
8	P2K1S2	6,58	7,4
9	P3K1S2	6,81	8,8
10	P1K2S2	6,31	11,4
11	P2K2S2	6,26	7,1
12	P3K2S2	6,80	9,1

Changes in moisture content during storage indicated a significant influence of the combination of processing techniques, packaging types, and storage conditions. In treatment P1 (non-blanching + shade drying), the moisture content tended to be higher than in the oven-drying treatments. This was evident in

samples P1K1S1 and P1K2S1, which had moisture contents of 11.3% and 11.2% (Table 1) in the second week, with only slight decreases observed in the fourth week. This finding suggests that shade drying is less effective in reducing moisture content, as the relatively low ambient temperature leads to slower water evaporation. Such conditions allow bound water within the leaf tissues to remain trapped and potentially reabsorbed during storage. This result aligns with previous literature, which emphasizes that drying and storage under low-humidity conditions are essential for maintaining the stability of herbal materials (Jayani et al., 2021).

Table 2 shows the infusion pH values and moisture content of cat's whiskers herbal tea after four weeks of storage under different processing, packaging, and storage treatments. The pH values ranged from 6.20 to 6.92, indicating that all samples remained slightly acidic and relatively stable throughout the storage period. Samples produced using oven-drying without blanching (P3), such as P3K1S1 and P3K2S1, generally exhibited slightly higher pH values, suggesting that the absence of blanching may allow more organic compounds to be retained, thereby reducing acidification during storage. Conversely, samples stored under cold conditions (S2), particularly P1K1S2 and P2K2S2, tended to have lower pH values, indicating that chilled storage slows biochemical and oxidative reactions that could influence acidity. Overall, the data indicate that the combination of blanching, oven drying, high-barrier packaging, and cold storage provides the most favorable outcome in maintaining product stability after four weeks. Among all treatments, sample P2K2S2 can be considered the most optimal due to its low moisture content and stable pH, suggesting better preservation of quality attributes essential for herbal tea safety and shelf-life.

The moisture content of the products varied more noticeably among treatments, ranging from 7.1% to 11.7%. The lowest moisture contents were consistently found in samples processed with blanching followed by oven drying and packaged in standing pouches, particularly under cold storage (e.g., P2K2S2 = 7.1% and P2K1S2 = 7.4%). This result demonstrates that blanching and controlled thermal drying are effective in reducing residual water content, while cold storage contributes to moisture stability during the shelf-life period. In contrast, higher moisture contents above the recommended limit of ≤10% were observed in several shade-dried samples and those stored at ambient temperature, such as P1K2S1 (11.6%) and P3K1S1 (11.7%). These treatments are more susceptible to moisture reabsorption from the surrounding environment, which may increase the risk of physical and microbiological deterioration over prolonged storage.

Different results were observed in treatments P2 (blanching + oven-drying at 60°C) and P3 (non-blanching + oven-drying at 60°C), which produced lower and more stable moisture levels. This condition was evident in samples P2K2S2 and P3K2S2, which were packaged in standing pouches with zipper seals (K2) and stored under cold conditions (S2 ≈ 4°C), showing moisture contents below 9.1% (Table 2) in the fourth week. These findings indicate that oven drying at 60°C was effective in reducing moisture to a safe level and maintaining its stability during storage. Furthermore, airtight packaging combined with low-temperature storage minimized moisture absorption from the environment, consistent with reports on the influence of packaging and temperature on moisture retention in dried materials.

Based on the moisture content analysis across treatments, differences between open packaging (K1) and sealed packaging (K2) were also clearly observed. In open packaging, moisture content tended to increase or fluctuate during storage, especially at room temperature (S1 ≈ 25°C). This condition was reflected in the moisture content of P3K1S1, which increased from 10.2% to 11.7% (Table 2) after four weeks, whereas the combination P3K2S2 maintained stable moisture at around 10.2%. This indicates that sealed packaging made of moisture-barrier materials effectively prevents water vapor absorption from the air and maintains product stability. Related studies have found that appropriate packaging materials and temperature control strongly influence moisture retention and the overall quality of herbal products during storage.

Meanwhile, the pH values of the tea infusions showed only slight changes during storage. In the second week, infusion pH ranged from 6.45 to 6.92 (Table 1) and showed a slight decrease in the fourth week for some treatments, particularly those stored at room temperature in open packaging. This decline in pH indicates the oxidation of phenolic compounds and the formation of organic acids during storage. For instance, sample P1K1S1 (non-blanching, open packaging, room temperature) had a pH of 6.46 in the second week and showed a slight decrease by the fourth week, whereas treatment P3K2S2 (oven drying without blanching, sealed packaging, cold storage) maintained a stable pH of 6.80 (Table 2) through the fourth week. These results highlight that rapid drying and low-temperature storage can preserve the chemical stability of the infusion. This finding is consistent with studies reporting that low-temperature storage slows the degradation of chemical components in herbal teas (Cai et al., 2023).

The relationship between moisture content and pH is also interconnected. Samples with higher moisture content tended to exhibit slight decreases in pH due to increased humidity, which may trigger chemical reactions and mild enzymatic activity. Conversely, samples with lower moisture content showed better pH stability because chemical reactions proceed more slowly under dry conditions. Therefore, it can be concluded

that the combination of oven drying at 60°C (P2 or P3), airtight packaging (K2), and cold storage (S2) was the most effective in maintaining the stability of moisture content and pH in cat's whiskers herbal tea. Overall, these findings strengthen the understanding that proper thermal processing, moisture-barrier packaging, and low-temperature storage are key strategies for preserving the physical and chemical quality of herbal tea products.

Color of Dried Samples and Infusion Color of Cat's Whiskers Herbal Tea

The measurements of the color of dried cat's whiskers leaves and the color of the tea infusion showed variations influenced by processing techniques (P), packaging types (K), and storage conditions (S) (Figure 2). In general, the values of L* (lightness), a* (red–green axis), and b* (yellow–blue axis) changed both after processing and throughout the storage period.

The color values of the dried samples showed that the oven-drying treatments (P2 and P3) tended to produce leaves with slightly lower L* values (darker appearance) compared to shade drying (P1), with L* values ranging from 44.26 to 52.50 and b* values ranging from 8.39 to 12.30 (Table 3). The decrease in brightness in oven-dried leaves is attributed to non-enzymatic browning reactions and possible chlorophyll degradation during heating. However, the blanching treatment prior to oven drying (P2) produced relatively brighter color compared to the non-blanched oven treatment (P3), as blanching inactivates polyphenol oxidase enzymes and slows the oxidation of green pigments. This finding is consistent with previous studies reporting that blanching prior to drying helps maintain the color stability of herbal tea leaves by reducing enzymatic browning activity (Handarini et al., 2022).

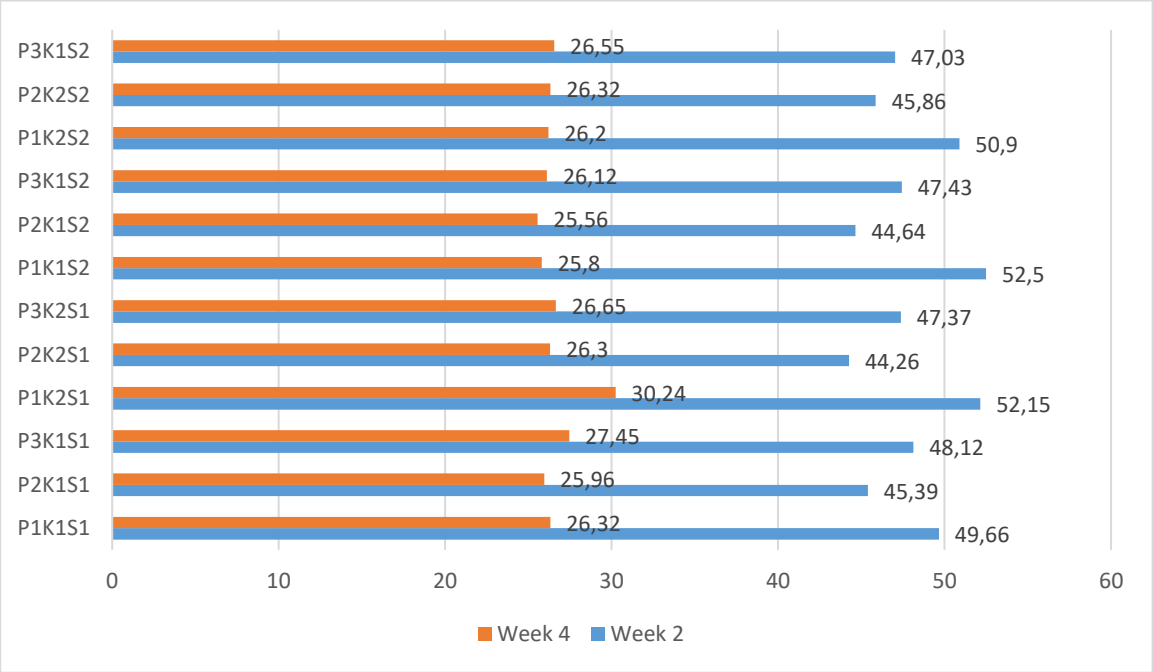

Figure 2. Comparison of infusion brightness between the second and fourth weeks

The a* values of all dried samples were negative, ranging from –7.25 to –3.59 (Table 3), indicating the dominance of the natural green color of cat's whiskers leaves, whereas the positive b* values, ranging from 8.39 to 12.30 (Table 3), reflect the tendency toward yellow tones. The yellowish appearance increased in oven-dried samples (P2 and P3) due to the transformation of chlorophyll into pheophytin as a result of heating.

According to Wahyuni et al. (2023), high-temperature drying tends to reduce the intensity of green coloration while increasing the b* value due to the formation of pigments resulting from chlorophyll degradation. When compared to the infusion color (Table 4), there is a decrease in L* values to 25.56–30.24 and a shift in a* values in several samples. For instance, in sample P1K2S1, the a* value shifts from negative (a* = –7.25) (Table 3) to positive (a* = 7.61) (Table 4). This shift indicates the occurrence of polyphenol and flavonoid oxidation reactions, which produce a more brownish color in the infusion. The b* values of the infusions range from 1.45 to 7.86 (Table 4), indicating that most infusion colors fall within the range of light yellow to yellowish brown, which is a typical characteristic of cat's whiskers herbal tea. This coloration is

influenced by heat treatment and oxidation during brewing, which lower the L* value and intensify the yellowish tone of the herbal tea.

Table 3. Comparison of a* Color Parameter (Red-Green) Between the Fourth and Second Weeks

Sample Code	Week 2	Week 4	Δa*
P1K1S1	-7.14	-4.1	+3.0
P2K1S1	-4.75	-5.27	-0.5
P3K1S1	-4.03	0.37	+4.4
P1K2S1	-7.25	7.61	+14.86
P2K2S1	-4.24	-4.49	-0.25
P3K2S1	-3.79	-2.63	+1.16
P1K1S2	-7.21	-4.04	+3.17
P2K1S2	-4.46	-2.83	+1.63
P3K1S2	-3.28	-2.16	+1.12
P1K2S2	-6.86	-1.4	+5.46
P2K2S2	-4.32	-4.1	+0.22
P3K1S2	-3.59	-3.77	-0.18

All samples initially exhibited negative a* values, confirming that the dried leaves still retained a dominant green hue during the early stage of storage. However, most samples showed an increase in a* values after four weeks, indicating a gradual reduction in greenness due to pigment degradation. This change reflects the breakdown of chlorophyll into pheophytin caused by oxidation during storage, resulting in a less intense green coloration and, in some cases, a slight shift toward red tones. Among the treatments, samples stored in packaging K1 generally maintained more negative a* values, suggesting better color preservation compared to those in K2, which experienced stronger shifts toward positive values. In particular, the P1K2S1 sample demonstrated the largest increase toward the red direction, implying that the combination of processing P1 and packaging K2 was less effective in protecting chlorophyll pigments. Conversely, samples processed with the P3 method tended to exhibit smaller changes in a* values, indicating improved color stability. Overall, these results emphasize that both processing methods and packaging types interactively influence the chromatic quality of herbal tea products during storage.

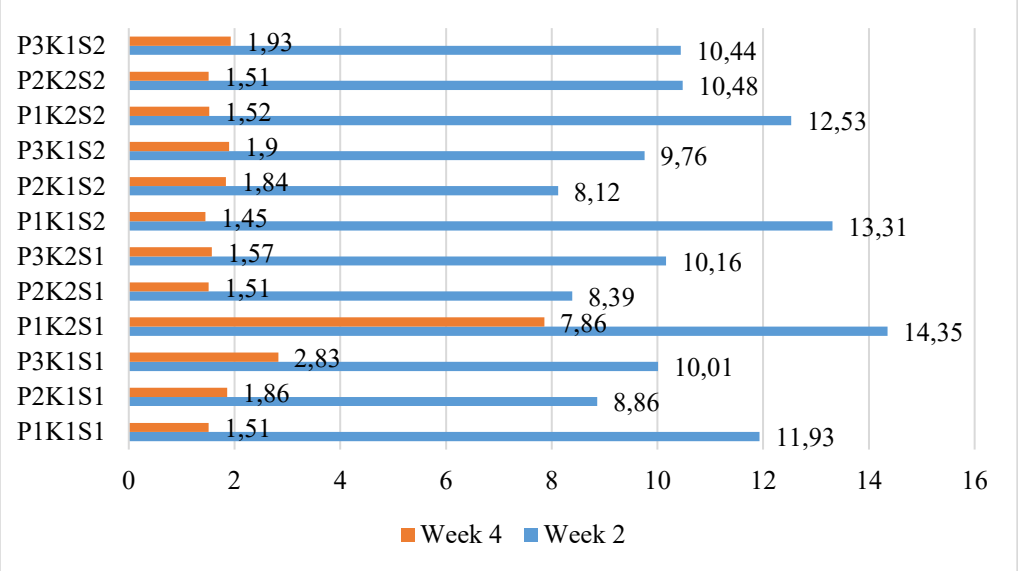

Figure 3. Comparison of b* color parameter (yellow-blue) between the fourth and second weeks

Dry Color (L*) indicates the lightness of the dried tea leaves, where higher values show a brighter appearance. Dry Color (a*) reflects the red-green tone, with positive values indicating more reddish coloration. Dry Color (b*) represents the yellow-blue tone, where higher scores show a stronger yellow hue. These three parameters describe the visual quality of the product after processing and drying. Brewed Color (L*) measures

the lightness of the tea infusion, showing how clear or dark the beverage appears. Brewed Color (a*) indicates the red-green intensity in the infusion, while Brewed Color (b*) shows its shift toward yellow. These three brewed-color parameters are used to evaluate the impact of processing, packaging, and storage on the visual quality of the final herbal tea product.

The oven-drying treatment with blanching (P2) in the comparison chart shows the most stable results for both dried samples and infusions. This is reflected in the relatively small differences in L* and a* values between dried leaves and brewed tea. Meanwhile, the treatment without blanching and with shade drying (P1) shows the greatest color change after infusion, as pigment oxidation proceeds more actively. The infusion color of P1 also appears darker compared with P2 and P3, indicated by a sharper decline in L* values.

The type of packaging and storage temperature also influence color stability. Samples stored in closed packaging (K2) at cold temperatures (S2) maintained higher L* and b* values compared to those in open packaging (K1) at room temperature (S1). This indicates that pigment oxidation occurs more slowly under low-oxygen and low-temperature conditions. Related research on color stability also found that airtight packaging with low-temperature storage slowed the color degradation of moringa herbal tea by up to 30% compared to open packaging (Fajriani et al., 2022).

Table 4. Color Analysis Results of Dried Cat's Whiskers Herbal Tea Samples

Name	L*	C*	Hº	a*	b*	dE*	dL*	da*	db*
Standard sample	0.00	11.52	88.73	0.26	11.51	0.00	0.00	0.00	0.00
P1K1S1	49.66	13.90	120.91	-7.14	11.93	50.21	49.66	-7.40	0.42
P2K1S1	45.39	10.05	118.19	-4.75	8.86	45.74	45.39	-5.01	-2.65
P3K1S1	48.12	10.79	111.95	-4.03	10.01	48.34	48.12	-4.29	-1.50
P1K2S1	52.15	16.07	116.81	-7.25	14.35	52.76	52.15	-7.51	2.83
P2K2S1	44.26	9.40	116.83	-4.24	8.39	44.60	44.26	-4.50	-3.12
P3K2S1	47.37	10.85	110.44	-3.79	10.16	47.56	47.37	-4.05	-1.35
P1K1S2	52.50	15.14	118.43	-7.21	13.31	53.06	52.50	-7.47	1.80
P2K1S2	44.64	9.27	118.77	-4.46	8.12	45.01	44.64	-4.72	-3.39
P3K1S2	47.43	10.30	108.56	-3.28	9.76	47.60	47.43	-3.53	-1.75
P1K2S2	50.90	14.29	118.71	-6.86	12.53	51.41	50.90	-7.12	1.02
P2K2S2	45.86	11.33	112.42	-4.32	10.48	46.10	45.86	-4.58	-1.04
P3K1S2	47.03	11.04	108.97	-3.59	10.44	47.20	47.03	-3.85	-1.07

Overall, the results for both dried color and infusion color show a consistent pattern of change: the higher the drying temperature and the more open the storage condition, the lower the L* value and the higher the a* value (indicating darker/more brownish color). The combination of treatment P2 (blanching + oven drying at 60 °C), closed packaging (K2), and cold storage (S2) proved to be the most effective in maintaining the color stability of both the dried leaves and the infusion of cat's whiskers herbal tea. This stable color not only serves as an indicator of good physical quality but also reflects the stability of bioactive compounds such as flavonoids and chlorophyll, which contribute to the antioxidant activity of cat's whiskers leaves.

All tea brew samples exhibited markedly higher L* values compared with the standard sample, ranging from 25 to 30. This result indicates that the applied processing, packaging, and storage treatments substantially enhanced the lightness of the tea brew, producing a visibly brighter appearance. Variation in hue was also evident from the Hº values, which ranged between 82.64 and 161.44. These differences demonstrate a shift in color from the typical greenish-yellow of herbal beverages toward a more brownish-red tone under certain conditions, particularly in samples stored using packaging type K2 during the first week (e.g., P1K2S1 with Hº = 45.90). The predominantly negative a* values confirm that the color of the brew tended toward a green direction, while the relatively low b* values indicate a weak yellowish intensity. Furthermore, the total color difference (ΔE*) values ranged from 27.50 to 31.34, which represents a highly noticeable change from the standard sample and can be easily perceived visually. The highest ΔE* value was observed in sample P1K2S1, suggesting that the combination of processing method P1 and packaging type K2 in the first storage period induced the most substantial alteration in color. Overall, these findings demonstrate that the visual attributes of cat's whiskers herbal tea brew are strongly influenced by post-harvest handling, showing that the selection of appropriate processing and packaging methods is essential to maintain the desired color quality of the final beverage product.

Table 5. Color Test Results of Cat's Whiskers Herbal Tea Brew Samples

Name	L*	C*	H°	a*	b*	dE*	dL*	da*	db*
Standard sample	0.00	11.52	88.73	0.26	11.51	0.00	0.00	0.00	0.00
P1K1S1	26.32	4.37	159.76	-4.10	1.51	28.49	26.32	-4.36	-10.00
P2K1S1	25.96	5.59	160.54	-5.27	1.86	28.24	25.96	-5.53	-9.65
P3K1S1	27.45	2.85	82.64	0.37	2.83	28.79	27.45	0.11	-8.68
P1K2S1	30.24	10.94	45.90	7.61	7.86	31.34	30.24	7.36	-3.66
P2K2S1	26.30	4.74	161.44	-4.49	1.51	28.53	26.30	-4.75	-10.00
P3K2S1	26.65	3.06	149.23	-2.63	1.57	28.59	26.65	-2.89	-9.95
P1K1S2	25.80	4.29	160.24	-4.04	1.45	28.03	25.80	-4.30	-10.06
P2K1S2	25.56	3.37	146.95	-2.83	1.84	27.50	25.56	-3.09	-9.67
P3K1S2	26.12	2.88	138.60	-2.16	1.90	27.94	26.12	-2.42	-9.61
P1K2S2	26.20	2.07	132.65	-1.40	1.52	28.09	26.20	-1.66	-9.99
P2K2S2	26.32	4.37	159.76	-4.10	1.51	28.49	26.32	-4.36	-10.00
P3K2S2	26.55	4.23	152.80	-3.77	1.93	28.51	26.55	-4.02	-9.58

Analysis of Variance

Moisture Content and Infusion pH

The ANOVA results show that processing (P), packaging (K), and storage (S) treatments exert different levels of influence on the physicochemical characteristics of cat's whiskers herbal tea. Moisture content was significantly affected by all three treatments ($p < 0.05$), indicating that differences in processing method, packaging material, and storage duration had a meaningful impact on water content stability in the product. Meanwhile, the infusion pH did not show any significant differences across treatments ($p > 0.05$), suggesting that pH remained relatively stable regardless of processing, packaging, or storage conditions.

For the dry color attributes, only L* and b* were significantly influenced by processing and packaging, implying that these treatments affected lightness and yellow intensity of the dried leaves. However, storage did not produce significant differences in the dry color parameters, and the a* value was not significantly influenced by any treatment. In the brewed tea color, only processing significantly affected L* and b*, showing that processing contributed to changes in lightness and yellowish tone of the infusion. Both packaging and storage did not cause significant changes in any of the brewed-color parameters. Overall, the findings indicate that processing plays the most dominant role in determining moisture content and color quality, while packaging has a secondary effect, and storage duration shows a minimal influence on product characteristics.

The results of the analysis of variance (ANOVA) showed that the processing factor (P), packaging type (K), and storage conditions (S) had a significant effect on moisture content ($p < 0.05$), but no significant effect on infusion pH ($p > 0.05$). The moisture content of the cat's whiskers herbal tea product ranged from 6.8% to 11.7%, while the infusion pH values were between 6.20 and 6.92. The highest moisture content was obtained from treatment P1K1S1 (non-blanched + shade drying, open packaging, room temperature), at 11.3%, while the lowest moisture content was found in P2K2S2 (blanching + oven drying at 60°C, closed packaging, cold temperature), at 6.8% (Table 1). Based on DMRT analysis ($\alpha = 0.05$), treatments P2K2S2 and P3K2S2 showed no significant difference. This indicates the effectiveness of oven drying and airtight packaging in maintaining low and stable moisture content.

Blanching prior to oven drying helps deactivate polyphenol oxidase enzymes that may trigger active compound degradation and accelerate rehydration during storage (Handarini et al., 2022). In addition, storage at cold temperatures (±4°C) slows vapor diffusion and inhibits microbial growth, thereby maintaining material moisture stability. Previous studies have shown that the combination of moderate thermal drying (60°C) and airtight packaging can reduce moisture fluctuations by up to 30% compared to room-temperature storage (Wahyuni et al., 2023).

The relatively constant pH values indicate that the processing and storage treatments did not affect the acidity stability of the infusion. This suggests chemical stability of active compounds such as sinensetin and rosmarinic acid, which contribute to the antioxidant activity of cat's whiskers leaves (Jayani et al., 2021). pH stability also correlates with low moisture content, as high moisture can accelerate phenolic oxidation and the formation of organic acids (Lisboa et al., 2022).

This study demonstrates that the quality attributes of Orthosiphon aristatus herbal tea are influenced differently by each treatment factor. The moisture content of the dried leaves remained below the national quality standard threshold, indicating that all samples were suitable for consumption as herbal tea products. Processing was identified as the major determinant of color changes in both dried samples and tea infusions, particularly for the lightness (L*) and yellowness (b*) parameters. In contrast, infusion pH and the a* color

parameter showed relatively stable values and were not significantly affected by packaging type or storage conditions up to the fourth week. Overall, the stability of the visual and chemical quality of the herbal tea is primarily governed by the initial processing method rather than post-processing storage factors. These findings highlight the importance of optimizing processing techniques to maintain the quality of O. aristatus herbal tea during storage.

Color of Dried Leaves and Infusion Color

Both dried leaf color and infusion color parameters showed significant changes, particularly in L* (lightness) and b* (yellowness) values ($p < 0,05$). The L* values of dried leaves ranged from 44.26 to 52.50, while b* values ranged from 8.39 to 12.30 (Table 3). Oven-dried leaves (P2 and P3) exhibited darker colors than shade-dried leaves (P1), but the colors were more stable during storage. This was due to non-enzymatic browning reactions and chlorophyll degradation caused by heating, which was offset by reduced enzymatic oxidation because of blanching (Handarini et al., 2022).

Samples treated with P2K2S2 showed the best color stability, with the smallest decrease in L* value after four weeks of storage, whereas P1K1S1 experienced the largest reduction in brightness due to pigment oxidation. The increase in b* (yellowness) with thermal drying reflects the transformation of chlorophyll into pheophytin and carotenoid compounds due to moderate heating (Wahyuni et al., 2023).

For the infusion color, L* values were lower than those of dried leaves, indicating the dissolution of flavonoid and polyphenol pigments during brewing. b* values ranged from 1.45 to 7.86 (Table 4), showing the characteristic yellowish to brownish hues typical of cat's whiskers herbal tea. Infusions from treatments P2K2S2 and P3K2S2 had brighter and more stable colors compared to P1K1S1, which darkened more rapidly due to high moisture content and pigment oxidation. According to Fajriani et al. (2022), storage using airtight packaging at low temperatures can reduce color degradation by up to 25% compared with open packaging at room temperature. ANOVA results also showed that the a* value (green–red axis) did not differ significantly ($p > 0.05$) for both dried leaves and infusion. This indicates green pigment stability during storage, suggesting that oxidation progressed slowly and did not cause drastic shifts in the red–green dimension.

Implications for Quality and Shelf Life

Overall, the combination P2K2S2 (blanching + oven drying at 60°C + closed packaging + cold temperature) is the most effective treatment for maintaining the physical and chemical quality of cat's whiskers herbal tea. This treatment produced low moisture content, stable pH, and the most stable color in both dried leaves and infusion during storage. The significant interaction among the three factors (P×K×S) on moisture content indicates a synergy between thermal drying processes, moisture vapor barriers provided by the packaging, and low storage temperatures in maintaining product quality.

The results of this study are consistent with and reinforce the findings of Taokaenchan et al. (2021), who demonstrated that appropriate drying conditions play a crucial role in preserving secondary metabolites of Orthosiphon aristatus, including total phenolics, flavonoids, and antioxidant activity. While Taokaenchan et al. highlighted 40°C as the optimum drying temperature for retaining bioactive compounds, the current study further emphasizes that preservation during storage also requires an integrated strategy combining thermal processing, suitable packaging, and controlled storage temperature.

Furthermore, this study is also in line with the findings of Faramayuda et al. (2022), who reported that the levels of phenolic and flavonoid compounds in Orthosiphon aristatus are strongly influenced by external factors, including environmental stressors and cultivation differences. Their study showed variations in polyphenol and flavonoid content between wild-type purple cat's whiskers leaves and callus culture, indicating that metabolic stability is highly dependent on production conditions. Compared to these findings, the current study contributes additional insight by showing that post-harvest handling (processing and storage) is equally decisive for maintaining the stability of bioactive compounds. Thus, in addition to cultivation strategies such as callus culture, optimizing drying, packaging, and storage conditions, as demonstrated by the P2K2S2 treatment, is crucial to ensure high-quality herbal tea products.

These findings reinforce those of Lisboa et al. (2022) and Jayani et al. (2021), who stated that layered processing and storage strategies (thermal + packaging + temperature) are key to maintaining the physical and chemical quality of dried herbal products. Therefore, the application of P2K2S2 can be recommended as a technical standard for processing cat's whiskers herbal tea aimed at improving quality, stabilizing bioactive compounds, and extending shelf life.

CONCLUSION

The results of the study show that processing techniques, packaging types, and storage conditions have a significant effect on the moisture content and color (L* and b*) of cat's whiskers herbal tea (Orthosiphon aristatus). The combination of blanching and oven drying at 60°C, packaged in a tightly sealed standing pouch with a zipper seal, and stored at cold temperature (±4°C) (P2K2S2) produced the best results, with low moisture content (~6.8%), neutral infusion pH (~6.3), bright dried leaf color (high L* and b* values), and a stable yellowish infusion color. These findings indicate that the application of mild thermal processing combined with airtight packaging and low-temperature storage effectively preserves the physical and chemical quality of cat's whiskers herbal tea.

The improved stability of moisture content and color in the P2K2S2 treatment is associated with the inactivation of browning enzymes during blanching, the efficiency of oven drying, and the reduced oxidation of pigments and phenolic compounds due to the use of closed packaging and low storage temperatures. This combination has been proven effective in extending shelf life, maintaining the product's visual appeal, and increasing the economic value of cat's whiskers herbal tea, particularly for small-scale producers in the Tana Toraja region.

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CONFLICT OF INTEREST

The authors confirm that they have no financial, professional, or personal connections that could have influenced the outcomes or interpretation of this research.

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