Poltekita: Jurnal Ilmu Kesehatan
e-ISSN: 2527-7170 | p-ISSN: 1907-459X
Volume 19 Issue 3, 2025, page 457-470
DOI: 10.33860/jik.v19i3.4327
Website:https://ojs.polkespalupress.id/index.php/JIK
Publisher: Poltekkes Kemenkes Palu

Antioxidant and Antibacterial Activities of Palu Local Shallot (*Allium cepa* var. *aggregatum* L.) Extracts Using Various Solvents

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ARTICLE INFO

Article History:
Received: 2025-10-14
Published: 2025-12-31

Keywords:
Palu local shallot; antioxidant; DPPH; metal chelation; antibacterial

ABSTRACT

Background: The Palu local shallot contains active compounds such as flavonoids and phenolics, which function as antioxidants to neutralize free radicals and possess antibacterial properties against pathogenic microbes. This study aimed to analyze and compare the phytochemical profile, total phenolic and flavonoid contents, antioxidant activity, metal-chelating capacity, and antibacterial potential of Palu local shallot extracts obtained using different solvents.
Methods A maceration extraction method was performed using n-hexane, ethyl acetate, and ethanol. Each extract underwent phytochemical screening, total phenolic and flavonoid quantification, antioxidant assessment via the DPPH method, metal-chelating evaluation, and antibacterial testing.
Results: The ethanol and ethyl acetate extracts contained alkaloids, flavonoids, saponins, tannins, and triterpenoids, while the n-hexane extract contained only alkaloids and triterpenoids. The ethyl acetate extract exhibited the highest phenolic content (30.35 ± 0.90 mg GAE/g), whereas the ethanol extract contained the highest flavonoid level (30.28 ± 0.57 mg QE/g). The strongest antioxidant activity was found in the ethanol extract (IC_{50} = 38.33 ± 1.85 µg/mL). The highest metal chelating activity is the ethanol extract (20.23 ± 0.54%). The ethyl acetate extract demonstrated the strongest antibacterial activity, yielding a 17.43 ± 0.85 mm inhibition zone.
Conclusion: Ethanol is the most effective solvent for extracting antioxidant compounds from Palu local shallots, while ethyl acetate yields the strongest antibacterial activity.

INTRODUCTION

Health problems in Indonesia are frequently linked to diseases caused by free radicals. Free radicals are generated through oxidation reactions, and one of their physiological functions is to eliminate harmful bacteria. However, when present in excessive amounts, they induce oxidative stress and damage cellular structures. In addition, bacteria are major contributors to various health issues such as infections, diarrhea, and digestive disorders (Fadlilah & Lestari, 2023; Miao et al., 2019).

The formation of free radicals can be inhibited by antioxidants (Nurkhasanah et al., 2023). Antioxidants are widely found in plants because they contain bioactive compounds such as flavonoids, alkaloids, and tannins, which serve as potent antioxidant sources (Juwita & Walanda, 2020). These active compounds also possess antibacterial potential. Antibacterial agents function by inhibiting the growth of or destroying bacteria through disruption of microbial metabolic

processes (Pertiwi et al., 2022), such as *Salmonella typhi* bacteria. This bacterium is commonly found in food materials such as raw eggs and meat or fruits and vegetables that are not washed thoroughly. If contaminated with this bacterium, it causes typhoid fever. If not handled properly, it can be fatal (Tobing, 2024).

Antioxidant and antibacterial properties can be found in numerous plant species, including the Palu local shallot, which contains flavonoid compounds such as quercetin (Misna & Diana, 2016). These bioactive compounds can be isolated through extraction processes. Plant metabolites exhibit different affinities depending on solvent polarity; therefore, solvents with varying polarity levels are required to efficiently extract these active constituents (Sembiring et al., 2016).

This research is relevant to food safety because shallots can be developed into natural preservatives for food because they are safer and more environmentally friendly natural preservatives. The active compounds in shallots can suppress the development of microorganisms and reduce the rate of oxidation processes, which ultimately extends the durability and shelf life of food products (Rahmawati et al, 2025). Shallots also contain flavonoid compounds such as quercetin, which act as antioxidants and antibacterials, and are capable of reducing the risk of cancer, heart disease, and diabetes (Jaelani, 2007; Misna dan Diana, 2016). The utilization of antioxidant compounds in shallots is very beneficial for local food to prevent free radicals, thereby improving immunity and public health (Hartoyo. 2020). Antioxidant compounds support the development of topical pharmaceutical preparations that can be easily used for the treatment of burn wounds. One of them is by administering cream preparations (Rahayu et al, 2019).

Studies on antioxidant activity using the DPPH method and antibacterial testing on shallots have been widely conducted. However, research that provides a more comprehensive analysis of shallots, such as total phenolic content, total flavonoid content, antioxidant activity through metal-chelating assays, extraction using different solvent polarities, and antibacterial assessment against foodborne pathogens, remains limited. Metal chelation needs to be done as another way to counteract free radicals. Metals such as iron, copper, and other transition metals participate in the Fenton reaction that produces highly reactive free radicals (Collin, 2019). Therefore, this study investigates the antioxidant activity (DPPH), metal-chelating capacity, total phenolic content, total flavonoid content, and antibacterial activity against *Salmonella typhi* of Palu local shallot (*Allium cepa* var. Aggregatum L.) extracts obtained using solvents of varying polarity (n-hexane, ethyl acetate, and ethanol).

METHODS

This study employed an experimental approach using a Completely Randomized Design (CRD) with three replications and three types of solvents, namely n-hexane, ethyl acetate, and ethanol. The observed variables included phytochemical screening (tests for alkaloids, flavonoids, saponins, tannins, triterpenoids, steroids, and quinones), total phenolic content, total flavonoid content, antioxidant activity using the DPPH method and a metal-chelating assay, as well as antibacterial activity.

The materials used in this study consisted of Palu local shallots (*Allium cepa* Var. Aggregatum L.), n-hexane, ethyl acetate, ethanol, distilled water, HCl, Dragendorff reagent, Mg powder, $FeCl_3$, CH_3COOH, H_2SO_4, NaOH, Folin-Ciocalteu reagent, Na_2CO_3, $AlCl_3$, DPPH powder, methanol, quercetin powder, $FeCl_2$, ferrozine, Salmonella-Shigella Agar (SSA), LB Broth, *Salmonella typhi* culture, NaCl, and Nutrient Agar (NA). The equipment used included a laboratory blender (waring type), vacuum evaporator, water bath, vortex mixer, incubator, UV-Vis spectrophotometer, cork borer, oven, inoculating loop, Bunsen burner, autoclave, forceps, and standard glassware commonly used in laboratory procedures.

The sample used in this research was Palu local shallots (*Allium cepa* Var. Aggregatum L.) harvested at 70 days of maturity from farmers in Kayumalue, Palu, Central Sulawesi. A total of 2 kg of shallots were collected in a single container, peeled (the inner skins were used for extraction), and washed thoroughly. The samples were then sliced into thin pieces of

approximately 0.5 cm and air-dried at room temperature for seven days without direct exposure to sunlight. Once dried, the shallots were ground using a waring laboratory blender and sieved through an 80-mesh filter. The percentage yield of the dried sample was then calculated (Suwardi, 2020).

The extraction process was carried out using a sequential maceration technique with three different solvents. The first extraction employed n-hexane by weighing 100 g of powdered shallot sample and placing it into a 1000 mL Erlenmeyer flask, followed by the addition of 500 mL of n-hexane (sample-to-solvent ratio of 1:5). The mixture was allowed to stand for 24 hours with occasional stirring and subsequently filtered using a vacuum filtration system. This maceration step was repeated twice. Filtrates from both cycles were combined and concentrated using a rotary vacuum evaporator to obtain the n-hexane extract. The resulting residue was air-dried and then subjected to further extraction using ethyl acetate followed by ethanol, following the same procedure as the n-hexane extraction. After obtaining extracts from each solvent, the yield percentage was calculated (Nurhaeni et al., 2019). The extract yield was determined using the following formula (Aristyanti et al., 2017):

$$\% \text{ Yield} = \frac{\text{Weight of Extract}}{\text{Weight of Simplicia}} \times 100\%$$

Phytochemical Screening

1. **Alkaloid Test**
   A total of 0.5 g of sample was mixed with 1 mL of 2 N HCl and 9 mL of distilled water. The mixture was heated for 2 minutes, allowed to cool, and then filtered. The filtrate was treated with 4-5 drops of Dragendorff reagent. The appearance of an orange or brick-red precipitate indicated the presence of alkaloids (Marjoni, 2016).
2. **Flavonoid Test**
   A total of 0.5 g of sample was added to 5 mL of ethanol and heated for 5 minutes. Several drops of concentrated HCl and 0.1 g of magnesium powder were then added. The formation of a yellow, orange, or red coloration confirmed the presence of flavonoids (Qurrota & Laily, 2011).
3. **Saponin Test**
   A total of 0.5 g of sample was combined with 10 mL of distilled water and boiled for 5 minutes, followed by filtration. The filtrate was shaken vigorously for 10 minutes and then treated with 1 mL of 2 N HCl. The appearance of stable, persistent foam indicated a positive result for saponins (Nugrahani et al., 2016).
4. **Tannin Test**
   A total of 0.5 g of sample was added to 5 mL of ethanol and filtered. Then, 2 mL of filtrate was mixed with 1 mL of 1% $FeCl_3$ solution. The development of a dark green or bluish-black color indicated the presence of tannins (Qurrota & Laily, 2011).
5. **Triterpenoid and Steroid Test**
   A total of 0.5 g of sample was dissolved in glacial acetic acid and then mixed with 1 mL of concentrated H_2SO_4. A blue or green coloration indicated the presence of steroids, whereas red or purple coloration indicated the presence of triterpenoids (Dapas et al., 2014).
6. **Quinone Test**
   A total of 0.5 g of sample was added to 5 mL of ethanol, heated in a water bath, and then filtered. The filtrate was treated with 4-5 drops of 5% NaOH solution. The formation of a red coloration indicated the presence of quinones (Noer, 2016).

Total Phenolic Content Analysis

A total of 0.5 mL of the diluted sample was mixed with 2.5 mL of diluted Folin-Ciocalteu reagent (1:10) and vortexed (Wolfe et al., 2003). The mixture was then treated with 2 mL of 7.5% Na_2CO_3 solution and vortexed again. The reaction mixture was incubated for 30 minutes in the dark. Absorbance was measured at 765 nm using a UV-Vis spectrophotometer. A gallic acid

standard curve was prepared following the same procedure used for the sample. The total phenolic content was expressed as milligrams of gallic acid equivalent (mg GAE) (Martati et al., 2021). Total phenol can be calculated using the formula (Hidayatullah et al, 2023):

$$\text{Total Phenol (mg GAE/g extract)} = \frac{\text{Concentration (C)} \times \text{Volume (V)}}{\text{Sample Weight (m)}}$$

Total Flavonoid Content Analysis

A volume of 0.5 mL of sample was mixed with 2 mL of distilled water, followed by the addition of 0.15 mL of 5% $NaNO_2$ solution. The mixture was vortexed until homogeneous and incubated for 6 minutes. Subsequently, 0.15 mL of 10% $AlCl_3$ solution was added, vortexed, and incubated for another 6 minutes. This was followed by the addition of 1 mL of 1 M NaOH and 1.2 mL of distilled water. The mixture was vortexed again and incubated for 15 minutes. Absorbance was measured at 510 nm using a UV-Vis spectrophotometer. Total flavonoid content was expressed as milligrams of quercetin equivalent (Patel et al., 2010). Total flavonoid can be calculated using the formula (Hidayatullah et al, 2023):

$$\text{Total flavonoid (mg QE/g extract)} = \frac{\text{Concentration (C)} \times \text{Volume (V)}}{\text{Sample Weight (m)}}$$

Antioxidant Activity Analysis Using the DPPH Method

For each extract (n-hexane, ethyl acetate, and ethanol), 25 mg of sample was weighed and dissolved in a 25 mL volumetric flask using ethanol to obtain a stock solution with a concentration of 1000 ppm. From this stock solution, aliquots of 0.1, 0.3, 0.5, 0.7, and 0.9 mL were taken and diluted to 10 mL with ethanol to produce extract solutions of 10, 30, 50, 70, and 90 ppm. To determine antioxidant activity, 0.2 mL of each sample solution was transferred into a vial using a micropipette and mixed with 3.8 mL of 50 µM DPPH solution. The mixture was homogenized and incubated in the dark for 30 minutes. Absorbance was then measured at 517 nm using a UV-Vis spectrophotometer. The antioxidant activity of the sample was determined by calculating the percentage of DPPH radical inhibition using the following formula (Molyneux, n.d.):

$$\%\ \text{Inhibition} = \frac{\text{Absorbance of Control} - \text{Absorbance of Sample}}{\text{Absorbance of Control}} \times 100\%$$

The sample concentration and percent inhibition values were plotted on the x- and y-axes, respectively, to generate a linear regression equation ($y = ax + b$). This equation was then used to determine the IC_{50} value (inhibitory concentration 50%) by substituting $y = 50$, where x represents the IC_{50} value. The IC_{50} indicates the concentration required to reduce DPPH absorbance by 50% (Faidah et al., 2020).

Metal-Chelating Activity Analysis

Metal-chelating activity was determined by mixing 1 mL of shallot extract (150 µg/mL) with 0.05 mL of 2 mM $FeCl_2$ and 0.2 mL of 5 mM ferrozine. The total volume was adjusted to 4 mL using methanol. The mixture was then shaken at room temperature for 10 minutes. The absorbance was measured at 562 nm using a UV-Vis spectrophotometer. A control solution containing only $FeCl_2$ and ferrozine was prepared for comparison. The percentage of Fe^{2+} ferrozine complex inhibition was calculated using the following formula (Dinis et al., 1994):

$$\%\ \text{Metal Chelation} = \frac{\text{Absorbance of Control} - \text{Absorbance of Sample}}{\text{Absorbance of Control}} \times 100\%$$

Antibacterial Activity Analysis

1. **Equipment Sterilization**
   Glassware such as beakers, measuring cylinders, Erlenmeyer flasks, and test tubes, along with Petri dishes, sterile pipettes, inoculating loops, and stir rods, were washed with detergent, rinsed thoroughly with clean water, and air-dried. The dried equipment was wrapped in paper or plastic and sterilized using an autoclave for 15-30 minutes at 121°C under 2 atm pressure(Waluyo, 2008) (Waluyo, 2008).

2. **Preparation of Selective Medium**
   A total of 6 g of Salmonella-Shigella Agar (SSA) was dissolved in 100 mL of distilled water, stirred until completely dissolved, heated to boiling, and sterilized in an autoclave for 15 minutes at 121°C and 1 atm pressure (Sari, 2017).
3. **Inoculation on Selective Medium**
   Prepared SSA medium plates were labeled according to the sample. The inoculating loop was sterilized using a Bunsen burner flame, then used to collect the bacterial culture grown in LB Broth. The sample was streaked onto the SSA surface using the loop to distribute the bacterial colonies evenly. The plates were incubated at 37°C for 24 hours. After incubation, *Salmonella typhi* colonies appeared as transparent colonies with a black center. A single colony was selected using a sterile inoculating loop, then streaked onto fresh SSA medium for purification and rejuvenation. Plates were incubated again at 37°C for 24 hours (Sari, 2017).
4. **Antibacterial Activity Test**
   The antibacterial activity was assessed using the well-diffusion method. A total of 60 µL of *Salmonella typhi* inoculum was mixed with 20 mL of Nutrient Agar (NA) and poured into a Petri dish. After solidification, three wells were punched into the agar. Next, 20 µL of each shallot extract (n-hexane, ethyl acetate, and ethanol) was introduced into the wells and labeled accordingly. The plates were incubated at 37°C for 24 hours. Clear zones formed around the wells indicated antibacterial activity. The diameter of the inhibition zone was measured using a caliper (Wijayati et al., 2014). The inhibition zone was calculated using the formula (Tansil et al., 2016):

$$\text{Inhibition Zone Diameter (mm)} = \frac{\text{Dvertical} + \text{Dhorizontal}}{2} - \text{Dwell}$$

Data Analysis

The data obtained were analyzed statistically using Analysis of Variance (ANOVA). If significant differences were observed among treatments, further analysis was conducted using the Least Significant Difference (LSD) test at a 95% confidence level and Duncan's Multiple Range Test (DMRT). ANOVA was applied to total phenolic content, flavonoid content, DPPH antioxidant activity, and metal-chelating activity. Meanwhile, phytochemical screening and antibacterial results were analyzed descriptively or qualitatively.

RESULTS

A. Extraction Yield

The extraction yields of Palu local shallot using different solvents are presented in Table 1. Ethyl acetate produced the highest yield compared to n-hexane and ethanol.

Table 1. Yield of Palu local shallot extracts using different solvents

Extract	% Yield
n-Hexane	13.39
Ethyl Acetate	20.60
Ethanol	20.04

B. Phytochemical Screening

The phytochemical screening of Palu local shallot extracts using different solvents showed positive results for several bioactive compounds. The complete results are presented in Table 2.

Table 2. Phytochemical profile of Palu local shallot extracts in different solvents

Phytochemical Test	Extract Results		
	n-Hexane	Ethyl Acetate	Ethanol
Alkaloids	(+ +)	(+ + +)	(+ +)
Flavonoids	(-)	(+ +)	(++)
Saponins	(-)	(+)	(+ + +)
Tannins	(-)	(+ + +)	(+ + +)
Triterpenoids	(+ +)	(+ +)	(+ +)
Steroids	(-)	(-)	(-)
Quinones	(-)	(-)	(-)

C. Total Phenolic Content

The total phenolic content of Palu local shallot extracts obtained with different solvents is shown in Figure 1. Ethyl acetate yielded the highest total phenolic content compared with n-hexane and ethanol.

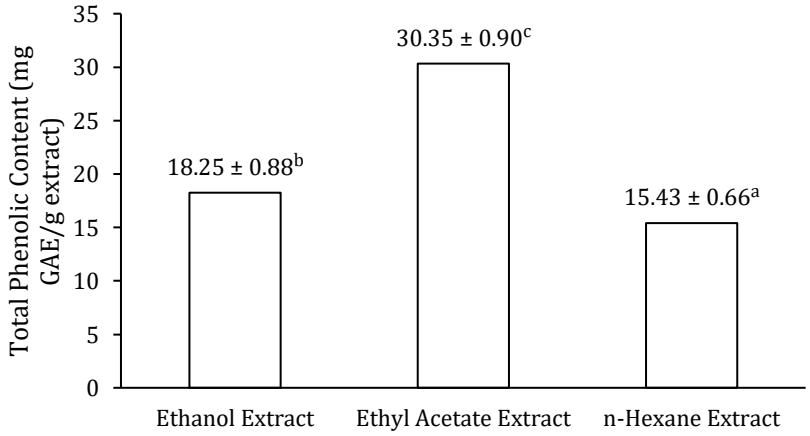

Figure 1. Results of total phenol from Palu shallot extract

D. Total Flavonoid Content

The total flavonoid content of Palu local shallot extracts using different solvents is presented in Figure 2. Ethanol produced the highest total flavonoid content compared to n-hexane and ethyl acetate.

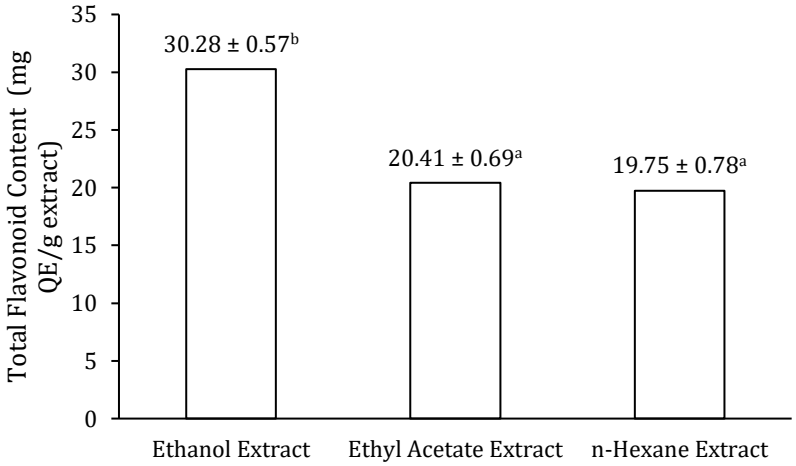

Figure 2. Results of total flavonoid from Palu shallot extract

E. Antioxidant Activity Using the DPPH Method

The antioxidant activity of Palu local shallot extracts obtained with various solvents, along with quercetin as a positive control, is shown in Table 3. Among the extracts, ethanol exhibited the lowest IC_{50} value, indicating the strongest antioxidant activity, compared with n-hexane and ethyl acetate.

Table 3. Results of IC50 value of Palu shallot extract

Treatment	IC_{50} Value (µg/mL)
Ethanol Extract	38.33 ± 1.85a*
Ethyl Acetate Extract	49.20 ± 1.84a
n-Hexane Extract	1009.40 ± 37.14b
Quercetin	25.38 ± 0.38a

*) Different superscript letters within the same column indicate significant differences among treatments ($p < 0.05$) as determined by DMRT

F. Metal-Chelating Activity

The metal-chelating activity of Palu local shallot extracts obtained using different solvents is presented in Figure 3. The ethanol extract exhibited the highest metal-chelating activity compared with n-hexane and ethyl acetate extracts.

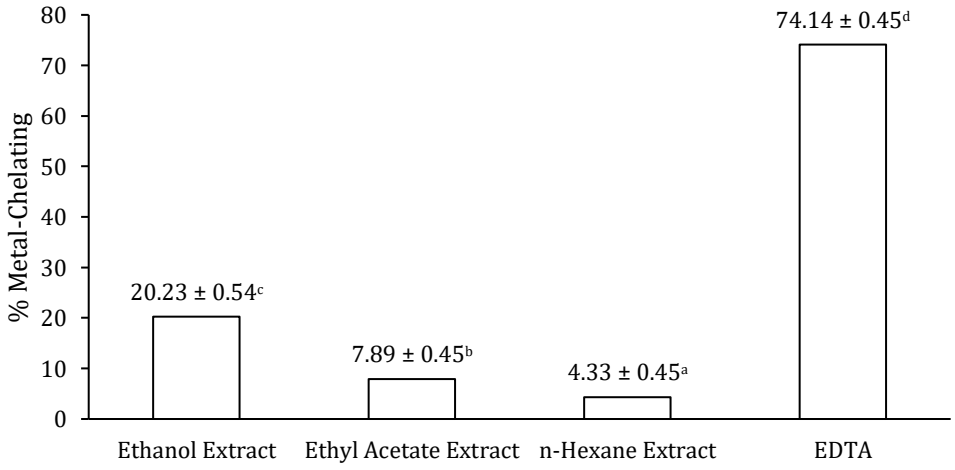

Figure 3. Results of metal chelating of Palu shallot extract

G. Antibacterial Activity

The antibacterial activity of Palu local shallot extracts in inhibiting the growth of *Salmonella typhi* is shown in Table 4. Among the tested solvents, ethyl acetate exhibited the strongest antibacterial activity compared with ethanol and n-hexane, as illustrated in Figure 4.

Table 4. Results of inhibition zone of Palu shallot extract

Treatment	Inhibition Zone (mm)	
	50% Concentration	100% Concentration
Ethanol Extract	4.39 ± 0.87	10.51 ± 0.76
Ethyl Acetate Extract	13.75 ± 0.18	17.43 ± 0.85
n-Hexane Extract	0	0

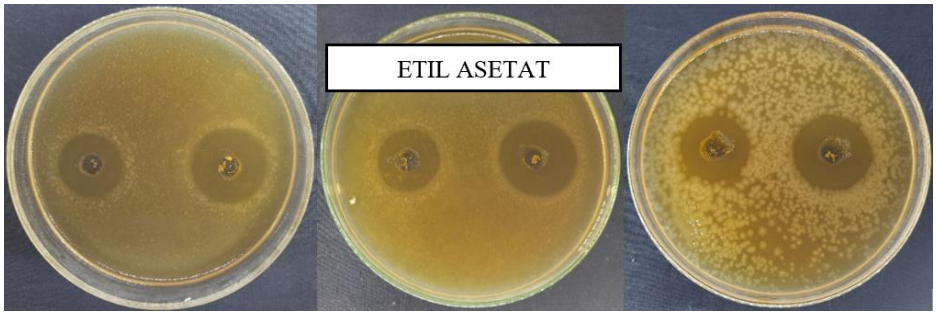

Figure 4. Results of inhibition zone of Salmonella typhi bacteria from ethyl acetate extract of Palu shallots

DISCUSSION

Extract Yield

The findings indicate that the highest extract yield was obtained from Palu local shallots extracted with ethyl acetate, reaching 20.60% as shown in Table 1. This is presumably due to the higher abundance of bioactive compounds in shallots that possess semipolar to polar characteristics compared with nonpolar constituents. This aligns with the "like dissolves like" principle, in which polar compounds are more soluble in polar solvents, semipolar compounds in semipolar solvents, and nonpolar compounds in nonpolar solvents.

The higher yield of the ethyl acetate extract compared with ethanol suggests that Palu shallots contain slightly more semipolar bioactive compounds than polar ones. Examples of such compounds include phenolic compounds and certain flavonoid subclasses (isoflavonoids, flavanones, and flavones) (Suhendra et al., 2019).

Variations in extract yield across the three solvents arise from differences in the polarity of secondary metabolites present in the plant material. These results are consistent with previous studies reporting that the highest yield of red onion peel extract was obtained using an ethanol-water solvent mixture (13.27%) (Badriyah & Farihah, 2022).

Phytochemical Screening

The phytochemical analysis showed that the n-hexane extract contained alkaloids and triterpenoids, while both ethyl acetate and ethanol extracts contained alkaloids, flavonoids, saponins, tannins, and triterpenoids (Table 2). This pattern is expected given that ethyl acetate and ethanol are capable of extracting polar and semipolar metabolites, whereas n-hexane selectively extracts nonpolar compounds.

The solubility of bioactive compounds in shallots depends on the match between solvent polarity and compound polarity. Ethanol is a polar solvent, ethyl acetate is semipolar, and n-hexane is nonpolar (Yani et al., 2023)

The plus signs in Table 2 represent qualitative estimates of phytochemical abundance based on observed intensities of color or precipitate formation (Sorescu et al., 2021). A minus sign

indicates the absence of the respective compound. Based on this scoring, n-hexane extracts showed moderate levels (++) of alkaloids and triterpenoids; ethyl acetate extracts exhibited high levels (+++) of alkaloids and tannins; and ethanol extracts showed high levels (+++) of saponins and tannins.

These results are consistent with other studies reporting that Palu shallot extracts obtained using n-hexane contain alkaloids, while ethyl acetate and ethanol extracts contain flavonoids, alkaloids, saponins, and tannins (Faidah et al., 2020). Other studies similarly reported that Palu shallots contain flavonoids, alkaloids, and tannins (Juwita & Walanda, 2020).

Total Phenolic Content

Statistical analysis indicated significant differences at $p < 0.05$. The total phenolic content of ethanol-extracted samples differed significantly from those extracted with ethyl acetate and n-hexane. The highest phenolic content was found in the ethyl acetate extract, amounting to 30.35 ± 0.90 mg GAE/g extract (Figure 1).

This is likely because ethyl acetate, being semipolar, is an optimal solvent for extracting semipolar phenolic compounds. These findings align with reports showing that semipolar fractions such as ethyl acetate and butanol contain the highest phenolic levels compared with ethanol and n-hexane fractions (Rondonuwu & Suryanto, 2017).

The presence of phenolics in the ethanol extract suggests that some polar phenolics (e.g., catechol and certain flavonoids) are also extracted by ethanol. Meanwhile, the small amount of phenolics detected in the n-hexane extract suggests the presence of nonpolar phenolics, such as α-tocopherol (vitamin E) (Yatheshappa et al., 2025).

The high phenolic content in the ethyl acetate extract indicates a substantial abundance of phenolic constituents in Palu shallots. Previous studies similarly reported that red onion peel extracted with ethanol contained 31.34 ± 2.28 mg GAE/g (Martati et al., 2021).

Total Flavonoid Content

Statistical tests showed significant differences at $p < 0.05$. Total flavonoid levels in the n-hexane extract were not significantly different from those in the ethyl acetate extract but differed significantly from the ethanol extract. The ethanol extract produced the highest total flavonoid content (30.28 ± 0.57 mg QE/g extract), followed by ethyl acetate and then n-hexane (Figure 2).

This is likely due to the strong ability of ethanol, a polar solvent, to extract polar flavonoids. The detectable flavonoid levels in ethyl acetate and n-hexane extracts suggest the presence of less polar flavonoids in shallots. Semipolar flavonoids such as flavones, flavanones, and flavonols can be extracted using semipolar solvents like ethyl acetate. Meanwhile, nonpolar flavonoids, such as polymethoxy aglycones or aglycone isoflavones lacking sugar moieties, can dissolve in n-hexane (Satria et al., 2022).

These results agree with other studies reporting flavonoid content in red onion peel extracts, including ethanol-extracted samples yielding 26.12 ± 0.75 mg QE/g (Martati et al., 2021).

Antioxidant Activity Using the DPPH Method

Statistical analysis showed significant differences at $p < 0.05$. IC_{50} values of extracts prepared with ethanol were not significantly different from those extracted with ethyl acetate or quercetin but differed significantly from n-hexane extracts. The ethanol extract exhibited the strongest antioxidant activity (IC_{50} = 38.33 ± 1.85 μg/mL), followed by ethyl acetate, while n-hexane showed the weakest activity (Table 3).

This is presumably due to the higher phenolic and flavonoid content in the ethanol extract, as demonstrated earlier (Figures 1 and 2). Higher phenolic and flavonoid levels contribute more hydroxyl groups capable of donating hydrogen atoms to neutralize DPPH radicals (Taroreh et al., 2016). Flavonoids deactivate free radicals through hydrogen donation mechanisms (Al Kausar et al., 2023). Other antioxidant compounds detected in the phytochemical screening (Table 2) may also contribute to the IC_{50} values.

IC_{50} values are inversely correlated with antioxidant activity. Lower IC_{50} values indicate stronger antioxidant potential (Mardiah et al., 2017). Antioxidant strength is categorized as: very

strong (IC_{50} < 50 μg/mL), strong (50-100 μg/mL), moderate (100-150 μg/mL), and weak (150-200 μg/mL) (Molyneux, 2003). Accordingly, the ethanol and ethyl acetate extracts of Palu shallots fall into the "very strong" antioxidant category.

Comparable findings reported ethanol extracts of red onion peel exhibiting IC_{50} values of 15.64 μg/mL (Mardiah et al., 2017). Another study reported that ethanol extracts of Palu valley shallots exhibited strong antioxidant activity with an IC_{50} of 38.55 μg/mL (Juwita & Walanda, 2020).

Metal-Chelating Activity

Statistical analysis revealed significant differences at $p < 0.05$. Metal-chelating activity in the ethanol extract differed significantly from ethyl acetate, n-hexane, and EDTA controls. The strongest activity was observed in the ethanol extract (20.23 ± 0.54%), followed by ethyl acetate, with the lowest activity shown by n-hexane (Figure 3).

The higher chelating activity of the ethanol extract may be attributed to its higher flavonoid and phenolic content. These compounds possess functional groups capable of binding metal ions. Phenolic hydroxyl and carboxyl groups can chelate Fe^{2+} ions and stabilize them (Alfreds, 2015).

Excess metal ions in the body can participate in Fenton reactions, producing highly reactive free radicals, particularly via Fe^{2+}. Chelation of Fe^{2+} can inhibit this process and reduce oxidative damage (Taroreh et al., 2016).

Although no prior studies specifically investigated metal-chelating properties of Palu shallots, similar research on different plant samples showed that methanol extracts of gedi leaves exhibited substantial chelating activity (48.07%) (Taroreh et al., 2016).

Antibacterial Activity

The results indicate that the highest antibacterial activity was demonstrated by the ethyl acetate extract, with inhibition zones of 13.75 ± 0.17 mm (50%) and 17.43 ± 0.85 mm (100%) against *Salmonella typhi*. Ethanol extract produced moderate inhibition, while n-hexane showed no antibacterial activity (Table 4). These findings correlate with the higher phenolic and flavonoid levels in the ethyl acetate extract (Figures 1 and 2).

Figure 4 shows clear inhibition zones around wells filled with ethyl acetate extract, confirming the antibacterial effect. Larger inhibition zones were produced at higher extract concentrations.

Variations in 50% and 100% concentrations were carried out to determine the effect of concentration on antibacterial activity. This is indicated by the results that the higher the concentration of shallot extract, the larger the clear zone (inhibition zone) formed because it can inhibit bacterial growth (Nurhayati dan Setiawan, 2018).

Ethyl acetate extracts displayed stronger antibacterial activity than ethanol extracts likely because semipolar solvents extract certain moderately polar antibacterial metabolites, including alkaloids, saponins, terpenoids, and steroids (Zulli et al., 2015). The absence of antibacterial activity in the n-hexane extract may reflect low or absent levels of antibacterial compounds, consistent with the phytochemical, phenolic, and flavonoid data.

Secondary metabolites such as flavonoids, alkaloids, tannins, saponins, and terpenoids have mechanisms including inhibition of nucleic acid synthesis, membrane disruption, metabolic interference, and cell wall damage, ultimately causing lysis and bacterial death (Milah et al., 2016).

Salmonella typhi was selected as the test organism because it is commonly found in food products such as raw eggs, meat, dairy, and unwashed produce, and is the causative agent of typhoid fever. This research used aquades as a negative control and 20% chloramphenicol as a positive control. Chloramphenicol, a broad-spectrum antibiotic, is commonly used to treat typhoid infections (Milah et al., 2016)(Pertiwi et al., 2022).

Although studies specifically examining the antibacterial activity of Palu shallots are limited, related research reported that ethanol extracts of red onion peel inhibited *S. typhi*, producing inhibition zones of 9.42 mm at 50% concentration (Octaviani et al., 2019).

CONCLUSION

Palu shallots in ethanol and ethyl acetate extracts contain alkaloid, flavonoid, saponin, tannin, and triterpenoid compounds, while the n-hexane extract contains alkaloids and triterpenoids. The highest total phenol is in ethyl acetate at 30.35±0.90 mg GAE/g extract. The highest total flavonoids are in the ethanol extract, at 30.28 ± 0.57 mg QE/g extract. The highest antioxidant activity (DPPH method) is the ethanol extract with an IC50 of 38.33 ± 1.85 µg/mL. The highest metal chelating activity is the ethanol extract at 20.23 ± 0.54%. The highest antibacterial activity is the ethyl acetate extract with an inhibition zone diameter of 17.42 ± 0.85 mm. Future research should develop research variables and use other methods to observe and enhance the potential of Palu shallots as antioxidants and antibacterials.

Author's Contribution Statement: Yudith Ayu Lestari; Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization; Mercy I. Riantiny Taroreh; Methodology, Writing - Review & Editing, Henny Adeleida Dien; Methodology, Writing - Review & Editing; Selvi Alfrida Mangundap; Supervision

Conflict of Interest: The authors declare no conflict of interest.

Source of Funding Statements: from independent costs**.**

Acknowledgements: The authors express their gratitude to the Master Program in Food Science, Sam Ratulangi University, for their support during project planning, and to Tadulako University for granting access to laboratory facilities at FKIP Chemistry and FMIPA Biology.

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