Antioxidant Analysis of Different Parts of Several Cultivars of Papaya (Carica Papaya L.)

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ABSTRACT
Research and development of natural antioxidants are gaining popularity with their wide application in food and medicine. Papaya (Carica papaya L.), a plant of medicinal and food value, is widely planted in tropical regions. This study was conducted to compare the tissues of different organs of papaya as well as the leaves and flowers of 9 cultivars of papaya. The three methods, namely, the 2,2'-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging assay, the 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) radical scavenging assay and the ferric reducing antioxidant power (FRAP) assay, were used to determine the total antioxidant activities. Also, the total phenolic content and the total flavonoid content were investigated to evaluate the antioxidant capacity. Our research shows that leaves and roots of papaya manifested higher antioxidant properties among all tested organs, and leaves and flowers of Daqing cultivar exhibited the strongest antioxidant ability. Overall, our results indicate papaya has the potential to become a natural antioxidant resource.

Introduction
Papaya (Carica papaya L.) originated in the tropical regions of South America, spread to the West Indies, and has been widely cultivated in tropical areas (Liu et al., 2007; Luan and Liu, 2006). Currently, Latin America, Asia and Africa are the main producing areas of papaya. Papaya is a tropical fruit with multiple values such as nutrition, medicine and health care (Liu et al., 2007). There are several kinds of nutrients in papaya (Azarkan et al., 2003; Hu and Pan, 2010), including enzymes, organic acids, saponins, sugars, fat, calcium, proteins and carotene (Almora et al., 2004; Wang et al., 2013; Zhang et al., 2001). As a medicinal plant, the seeds, fruits and leaves of papaya have been widely used in China. Papaya can protect the liver and stomach from disharmony (Wang et al., 2013) due to antibacterial, anti-inflammatory, and anti-aging properties (Dawkins et al., 2003); and it can scavenge oxidizing radicals (Murcia et al., 2001). Studies have indicated that traditional antioxidants such as total phenolic compounds, total flavonoids, vitamin C, and carotenoid contribute to its pharmacological activities (Meng et al., 2021; Mohamed et al., 2016). Recently, the overall production and harvested area of papaya around the world have gradually increased, indicating that market demand for papaya is increasing (Tang and Zheng, 2010), which is important for papaya cultivation, processing and utilization. In China, papaya is widely distributed in tropical and subtropical regions...
including Hainan, Yunnan, Guangdong and Taiwan. As a potential industry in Hainan (Liu and Wang, 2013), papaya has promising prospects for planting, storage, transportation, and processing. Combining its own characteristics and market, it is very important to use papaya to develop products, increase its additional value, as well as improve its industrial chain. Now, there are more than 10 cultivars of papaya in Hainan, China, including ‘Zhongbai,’ ‘Songbai,’ and ‘Dabai.’ In general, the extraction, processing and utilization of biologically active substances in papaya will make a significant contribution to the growth and enhancement of papaya functions (Qin, 2017), which has a wide range of applications in nutrition and health care.

According to scientific research, diseases such as cancer and aging are directly associated with oxidative damage. The studies on papaya antioxidation can help to understand the antioxidant and disease treatment potential of papaya as well as increase the values of papaya industry. The antioxidant activity of papaya seeds was examined by analyzing Hainan papaya seed extract and total antioxidant activity in terms of OH, O$_3$ and H$_2$O$_2$ scavenging (Zhou and Dai, 2009). The active substances in papaya leaves were extracted using solvents, and their antioxidant activities were explored (Du et al., 2016; Liu et al., 2017a). Certainly, many scholars have investigated the antioxidant capacity of processed papaya products, such as wine (Liu et al., 2017b) and sour milk beverage (Chen et al., 2018), providing references for papaya processing and utilization. However, there were few studies on the antioxidant activities and active substances present in different tissues and organs of papaya. The antioxidant activities of the pericarp and pulp were compared (Yuan, 2012); the antioxidant capacities in seeds, leaves and fruits of papaya were investigated (Maisarah et al., 2013). Nisa et al. (2019) explored the antioxidant activities in leaves of papaya with different varieties in Indonesia. The anti-cancer activities of leaf, peel, pulp, and seed extracts from papaya were explored (Hadadi et al., 2018). In-depth research on the antioxidant capacity of multiple parts and cultivars is needed.

As for the antioxidant activity assay, there is no standard method (Zhou et al., 2011) but three methods are widely used to understand the antioxidant capacity of foods: 2,2’-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity, 2,2’-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) radical scavenging activity and ferric reducing antioxidant power (FRAP) (Du et al., 2016). DPPH has absorption at a specific wavelength, and it will disappear after the absorption of hydrogen ions or electrons. The degree of the change is related to the degree of free radical scavenging, thus reflecting the antioxidant capacity. ABTS free radicals provide electrons when reacting with samples, and the amount of reaction reflects the antioxidant capacity. Antioxidant substances can reduce Fe$^{3+}$ to Fe$^{2+}$, and the total reduction capacity of the sample was reflected by tracking the amount of Fe$^{2+}$ inside (Du et al., 2016). The three methods can explore the antioxidant capacity of samples from three different perspectives, resulting in a comprehensive understanding of the antioxidant capacity of foods and natural products.

The antioxidant activities and active substances present in different tissues and organs of papaya as well as in the leaves and flowers of different cultivars of papaya were analyzed in this experiment in order to make maximum use of papaya resources. This study will serve as a conceptual framework for papaya implementation and exploitation in China and other nations, as well as a benchmark for production in the entire papaya extraction industry.

**Materials and Methods**

**Plant Materials**

Zhongbai cultivar papaya were obtained from the experimental teaching department of Hainan University for investigation of different parts of samples. The papaya used in this experiment had reached the “three lines yellow” stage of maturity (when three long yellow spots appear on the peel). The tissues including ripe pulp, immature pulp, ripe pericarp, and immature pericarp as well as organs including root, stem, leaf, flower, and seed, were collected.
For the test of leaves and flowers from different cultivars, ‘Wild Zhongbai,’ ‘Qing No. 7,’ ‘Tainong No. 8,’ ‘Dabai,’ ‘Daqing,’ ‘Jinshoulu,’ and ‘Zhongbai’ were obtained from a papaya company in Sanya, Hainan. ‘Zigeng’ and ‘Songbai’ were obtained from the papaya breeding center in Qizi Bay, Hainan.

**Key Instruments**

A ten-thousandth analytical balance (RADWAG AS220.R1, Poland), an air-dry oven (Yiheng DHG-9053A, Shanghai, China), a sample grinder (Long products, China), a UV-VIS spectrophotometer (Purkinje General T6, Beijing, China), a high-speed centrifuge (Shuke TGL-16S, Chengdu, China), an ultrasonic extractor (Shumei KQ5200E, Kunshan, China), and a water bath kettle (HH-4A, China) were used in this study.

**Extraction of Papaya Samples**

The papaya samples were dried and crushed before extraction, and 70% ethanol (7 mL) was mixed with four papaya samples (0.1 g). Then, the mixture was subjected to an ultrasonic extractor for 10 min and was centrifuged at 5000 r/sec at 35°C for 7 min. The supernatant was used for the subsequent measurements.

**DPPH Radical Scavenging Assay**

The DPPH radical scavenging activity test was performed according to Brand-Williams et al. (1995) with slight modifications (Bondet et al., 1997; Xie et al., 2015). The sample solution (25 μL) and 0.1 mM DPPH radical solution (2 mL) were thoroughly mixed, and the mixture was placed in darkness for 20 min. The absorbance was measured at 517 nm to determine the concentration of DPPH radical remaining in the solution. The 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox) was considered as the standard.

**ABTS Radical Scavenging Assay**

The ABTS scavenging determination was carried out as per Re et al. (1999). To generate ABTS radical cation (ABTS‘), a 7 mM solution of ABTS was reacted with 140 mM potassium phosphate at room temperature in the dark for 12–16 hours before use. The solution was diluted with ethanol to give an absorbance of 0.70 ± 0.02 at 732 nm. Then, the sample solution (25 μL) was fully mixed with the ABTS solution (2 mL) and reacted in darkness for 6 min. The results were expressed as the Trolox equivalent.

**FRAP Assay**

The FRAP determination method was carried out using Benzie and Strain’s methodology (1996). The FRAP test solution contained 10 mM 2,4,6-Tri(2-pyridyl)-s-triazine, 20 mM ferric chloride and 300 mM sodium acetate. The FRAP solution (1.8 mL) was mixed with the sample solution (10 μL) and incubated at 37°C for 10 min. The absorbance of the colored reaction product was measured at 593 nm, and Trolox was considered as the standard.

**Total Phenolic Content Assay**

The Folin-Ciocalteu technique was used to determine the total phenolic content (Singleton et al., 1999; Stevanato et al., 2004). The Folin-Ciocalteu reagent (0.5 mL) was mixed with distilled water (7.9 mL) and the sample extract (0.1 mL), and the mixture was neutralized with sodium carbonate (1.5 mL, 20%). After 2 hours in the dark, the absorbance at 765 nm was measured, and gallic acid was used as the standard.
**Total Flavonoid Content Assay**

The total flavonoids content was determined using ferric chloride coloration (Wang, 2014). Briefly, distilled water (5 mL) and the sample extract (1 mL) were combined and reacted with sodium nitrite (0.15 mL, 5%) for 6 min. The aluminum chloride (0.15 mL, 10%) was added and reacted for further 6 min. It was neutralized with sodium hydroxide (2 mL, 4%), and the mixture was reacted for another 15 min. The absorbance was measured at 420 nm with rutin as the standard, and the result was represented as a percentage.

**Statistical Analysis**

All tests were repeated three times, and the results were expressed as the mean ± standard deviation (SD). All data were examined with SPSS software and Duncan’s test ($P < .05$) was used for mean comparisons. The Pearson method was used to determine the correlation between antioxidant activity and total flavonoids and total phenols. The final results were obtained using a detailed evaluation of the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) comprehensive evaluation analysis (Opricovic and Tzeng, 2004; Sun et al., 2011). The evaluation indexes in the TOPSIS approach are rated according to how close they are to the idealized target.

**Results**

**Comparison of the Antioxidant Activities**

**DPPH Radical Scavenging Activity**

The DPPH radical scavenging activities of different tissues and organs ranged from 1.98 to 17.80 mmol·L⁻¹ Trolox·g⁻¹ DW (Figure 1a). Leaves and roots had the highest antioxidant activity (17.80 mmol·L⁻¹ Trolox·g⁻¹ DW, 14.07 mmol·L⁻¹ Trolox·g⁻¹ DW), which were significantly different from other part ($P < .05$), and seeds and pulp had the lowest activity. The activity in leaves of different cultivars ranged from 4.55 to 15.93 mmol·L⁻¹ Trolox·g⁻¹ DW (Figure 1b). The antioxidant activity in leaves was highest in ‘Songbai’ and ‘Zigeng,’ obviously different ($P < .05$) from the lowest in ‘Zhongbai’ (4.55 mmol·L⁻¹ Trolox·g⁻¹ DW). The antioxidant capacity of flowers ranged from 9.16 to 12.09 mmol·L⁻¹ Trolox·g⁻¹ DW (Figure 1c). The range of data changes was modest, indicating that there is no discernible difference in antioxidant capacity of flowers between some cultivars. Zigeng cultivar seemed to have the strongest possible level (12.09 mmol·L⁻¹ Trolox·g⁻¹ DW), followed by ‘Wild Zhongbai,’ and ‘Qing No. 7’ (9.16 mmol·L⁻¹ Trolox·g⁻¹ DW) manifested the lowest.

**ABTS Radical Scavenging Activity**

The ABTS values of different tissues and organs varied from 1.20 to 12.90 mmol·L⁻¹ Trolox·g⁻¹ DW (Figure 2a), which was consistent with the fluctuation range using DPPH radical scavenging assay. The roots (12.90 mmol·L⁻¹ Trolox·g⁻¹ DW) and leaves (12.82 mmol·L⁻¹ Trolox·g⁻¹ DW) were found to have the strongest antioxidant activities, significantly different from others ($P < .05$), while the seeds exhibited the lowest activity (1.20 mmol·L⁻¹ Trolox·g⁻¹ DW). The antioxidant activities of leaves ranged from 4.19 to 12.38 mmol·L⁻¹ Trolox·g⁻¹ DW (Figure 2b). The average antioxidant activity in ‘Qing No. 7’ and ‘Tainong No. 8’ papaya was the strongest, possessing significant statistical differences from others. The range for flowers from cultivars was much less (7.98–9.84 mmol·L⁻¹ Trolox·g⁻¹ DW) than for leaves, which was in line with the comparison results of the previous two assays (Figure 2c). The maximum activity was identified in ‘Zigeng’ (9.84 mmol·L⁻¹ Trolox·g⁻¹ DW), which was significantly different ($P < .05$) from ‘Qing No. 7,’ ‘Tainong No. 8’ and ‘Songbai.’
Figure 1. DPPH radical scavenging activities of different samples of *Carica papaya*. Different parts of papaya (a), Papaya leaves of several cultivars (b) and flowers of several cultivars (c). Trolox is considered as the standard and the correlation coefficient of the standard curve is 0.9978. Data are presented as the mean ± standard deviation (SD) of three replications. Different lowercase letters represent significant differences between different samples using Duncan’s test ($P < .05$).
Figure 2. ABTS radical scavenging activities of different samples of *Carica papaya*. Different parts of papaya (a). Papaya leaves of several cultivars (b) and flowers of several cultivars (c). Trolox is considered as the standard and the correlation coefficient of the standard curve is 0.9936. Data are presented as the mean ± standard deviation (SD) of three replications. Different lowercase letters represent significant differences between different samples using Duncan’s test (*P* < .05).
FRAP Value
As shown in Figure 3a, the FRAP values of different tissues and organs ranged from 8.83 to 49.30 mmol·L⁻¹ Trolox·g⁻¹ DW. The statistical differences manifested remarkable in different parts of papaya. Leaves of papaya exhibited the strongest antioxidant activity (49.30 mmol·L⁻¹ Trolox·g⁻¹ DW) compared to others (P < .05). The leaves had 5.58 times higher antioxidant activities than the ripe pulp, which was the lowest. The activities of the leaves from several cultivars ranged from 16.78 to 38.18 mmol·L⁻¹ Trolox·g⁻¹ DW (Figure 3b). ‘Daqing’ (38.18 mmol·L⁻¹ Trolox·g⁻¹ DW) and 'Jinshoulu' (37.06 mmol·L⁻¹ Trolox·g⁻¹ DW) exhibited equally high, significantly different from other cultivars, while ‘Zigeng’ and ‘Songbai’ were the lowest. When compared to the DPPH and ABTS methods, the antioxidant capacity of papaya flowers using the FRAP assay varied more widely (14.10–29.47 mmol·L⁻¹ Trolox·g⁻¹ DW) between different cultivars (Figure 3c), which could be attributed to differences in assay principles. The antioxidant activity of ‘Songbai’ and ‘Zigeng’ was the lowest, which was obviously different from other seven cultivars.

Comparison of the Active Antioxidant Substances
Total Phenolic Contents of Papaya
The results of different papaya tissues and organs as well as the leaves and flowers of various papaya cultivars were compared. Total phenolic contents ranged from 0.22% to 1.93% in various tissues and organs (Figure 4a). Papaya leaves had the greatest (P < .05) total phenolic content (1.93%), which was 8.77 times higher than seeds (0.22%). The values in leaves from different cultivars ranged from 0.37% to 1.98% (Figure 4b). ‘Jinshoulu’ (1.98%) and ‘Qing No. 7’ (1.95%) exhibited the highest (P < .05) phenolic contents when compared to others, especially the lowest one, ‘Zhongbai’ (0.37%). The flowers of ‘Wild Zhongbai’ showed the highest activity, followed by “Daqing,” significantly different (P < .05) from the lowest activity in ‘Songbai’ (0.74%).

Total Flavonoid Contents of Papaya
The total flavonoids content ranged from 0.17 to 2.34% (Figure 5a). Papaya leaves exhibited the highest, followed by the roots, significantly different (P < .05) from others, and seeds had the lowest (7.26% of leaves). The quantities found in the leaves of several cultivars ranged from 1.64 to 2.70% (Figure 5b). Both ‘Daqing’ (2.70%) and ‘Tainong No. 8’ (2.56%) showed the highest, possessing obvious statistical differences from other cultivars. The total flavonoids content of flowers ranged from 0.65 to 1.32% (Figure 5c). The flowers of ‘Wild Zhongbai’ manifested the highest (P < .05) activity (1.32%), and those of “Songbai” appeared at the lowest (0.65%).

Comprehensive Evaluation and Analysis
The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method was used to calculate the overall results, which were based on the five indexes, DPPH radical scavenging activity, ABTS radical scavenging activity, FRAP activity, total phenolic content and total flavonoid content.

It is exhibited that the antioxidant activities of the different tissues and organs in Carica papaya were in the order leaf > root > flower > stem > ripe pericarp > immature pericarp > ripe pulp > immature pulp > seed (Table 1).

Table 2 indicates that the order of the overall antioxidant activity of the papaya leaves from 9 cultivars decreased in the order ‘Daqing’ > ‘Qing No. 7’ > ‘Tainong No. 8’ > ‘Jinshoulu’ > ‘Dabai’ > ‘Zigeng’ > ‘Songbai’ > ‘Wild Zhongbai’ > ‘Zhongbai’.

The overall antioxidant activity of papaya flowers from 9 cultivars was ranked as follows: ‘Wild Zhongbai’ > ‘Zigeng’ > ‘Daqing’ > ‘Zhongbai’ > ‘Jinshoulu’ > ‘Tainong No. 8’ > ‘Dabai’ > ‘Qing No. 7’ > ‘Songbai’ (Table 3).
Figure 3. FRAP activities of different samples of Carica papaya. Different parts of papaya (a), Papaya leaves of several cultivars (b) and flowers of several cultivars (c). Trolox is considered as the standard and the correlation coefficient of the standard curve is 0.9863. Data are presented as the mean ± standard deviation (SD) of three replications. Different lowercase letters represent significant differences between different samples using Duncan’s test (P < .05).
Figure 4. Total phenolic contents of different samples of Carica papaya. Different parts of papaya (a). Papaya leaves of several cultivars (b) and flowers of several cultivars (c). Gallic acid is considered as the standard and the correlation coefficient of the standard curve is 0.9907. Data are presented as the mean ± standard deviation (SD) of three replications. Different lowercase letters represent significant differences between different samples using Duncan's test (P < .05).
Figure 5. Total flavonoid contents of different samples of Carica papaya. Different parts of papaya (a). Papaya leaves of several cultivars (b) and flowers of several cultivars (c). Rutin is considered as the standard and the correlation coefficient of the standard curve is 0.9966. Data are presented as the mean ± standard deviation (SD) of three replications. Different lowercase letters represent significant differences between different samples using Duncan’s test ($P < .05$).
Table 1. Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method for evaluating the antioxidant activities of different tissues and organs from *Carica papaya*.

| Part          | $D^+$  | $D^-$  | $C$       | Rank |
|---------------|--------|--------|-----------|------|
| Leaf          | 0.000  | 0.201  | 109963.325| 1    |
| Root          | 0.012  | 0.134  | 11.165    | 2    |
| Flower        | 0.044  | 0.061  | 1.377     | 3    |
| Stem          | 0.052  | 0.057  | 1.081     | 4    |
| Ripe pericarp | 0.118  | 0.016  | 0.132     | 5    |
| Immature pericarp | 0.120 | 0.015  | 0.125     | 6    |
| Ripe pulp     | 0.165  | 0.002  | 0.015     | 7    |
| Immature pulp | 0.171  | 0.001  | 0.009     | 8    |
| Seed          | 0.201  | 0.000  | 0.000     | 9    |

Note: The different parts of papaya were ranked based on how close to the idealized target. The tissue or organ, which was close to the best value of the ideal solution and was far away from the worst value of the negative ideal solution, was ranked first. $D^+$ represented the distance between the sample and the best value of the ideal solution, $D^-$ represented the distance from the worst value of the negative ideal solution, and C represented the relative proximity.

Table 2. TOPSIS method for evaluating the antioxidant activities of the *Carica papaya* leaves from 9 cultivars.

| Cultivar      | $D^+$  | $D^-$  | $C$      | Rank |
|---------------|--------|--------|----------|------|
| Daqing        | 0.007  | 0.149  | 22.093   | 1    |
| Qing No. 7    | 0.011  | 0.141  | 12.263   | 2    |
| Tainong No. 8 | 0.011  | 0.128  | 11.887   | 3    |
| Jinshoulu     | 0.03   | 0.121  | 4.03     | 4    |
| Dabai         | 0.041  | 0.07   | 1.704    | 5    |
| Zigeng        | 0.051  | 0.079  | 1.537    | 6    |
| Songbai       | 0.07   | 0.094  | 1.328    | 7    |
| Wild Zhongbai | 0.068  | 0.055  | 0.809    | 8    |
| Zhongbai      | 0.179  | 0.004  | 0.021    | 9    |

Note: The several cultivars of papaya leaves were ranked based on how close to the idealized target. The cultivar, who was close to the best value of the ideal solution and was far away from the worst value of the negative ideal solution, was ranked first. $D^+$ represented the distance between the sample and the best value of the ideal solution, $D^-$ represented the distance from the worst value of the negative ideal solution, and C represented the relative proximity.

Table 3. TOPSIS method for evaluating the antioxidant activities of the *Carica papaya* flowers from 9 cultivars.

| Cultivar  | $D^+$  | $D^-$  | $C$     | Rank |
|-----------|--------|--------|---------|------|
| Wild Zhongbai | 0.016  | 0.154  | 0.906   | 1    |
| Zigeng    | 0.033  | 0.104  | 0.756   | 2    |
| Daqing    | 0.039  | 0.069  | 0.639   | 3    |
| Zhongbai | 0.055  | 0.075  | 0.577   | 4    |
| Jinshoulu | 0.070  | 0.065  | 0.482   | 5    |
| Tainong No. 8 | 0.078  | 0.045  | 0.367   | 6    |
| Dabai     | 0.083  | 0.032  | 0.277   | 7    |
| Qing No. 7 | 0.119  | 0.031  | 0.205   | 8    |
| Songbai  | 0.138  | 0.019  | 0.120   | 9    |

Note: The several cultivars of papaya flowers were ranked based on how close to the idealized target. The cultivar, who was close to the best value of the ideal solution and was far away from the worst value of the negative ideal solution, was ranked first. $D^+$ represented the distance between the sample and the best value of the ideal solution, $D^-$ represented the distance from the worst value of the negative ideal solution, and C represented the relative proximity.
A comparison of the finding in Tables 2 and 3 indicates that the antioxidant capacities of ‘Wild Zhongbai’ were superior to those of cultivated ‘Zhongbai.’ It is generally recognized that wild species accumulate more antioxidants than cultivated species in order to adapt to severe environments (Song et al., 2014).

**Discussion**

Biological activities within the human body can generate a large number of oxygen free radicals, causing the human body to suffer from oxidative damage, thereby leading to human disorders and laying the seeds for the production of diseases (Galicia-Moreno and Gutiérrez-Reyes, 2014; Li et al., 2019; Venkataraman et al., 2013). The development and screening of antioxidants has become a contentious issue for scholars all over the world, and the characteristics and advantages of natural antioxidants are critical to the advancement of food and medicine (Xu et al., 2021). As a fruit with both nutritional and medicinal potential, papaya resources will be immensely important for the research and development of natural antioxidants. The contents of phenols and flavonoids in the leaves and stems of papaya were relatively high, which might be due to the exposure to the external environment and oxidative stress (Zhang et al., 2018); the roots of papaya exhibited stronger antioxidant properties to help plants resist adversities including drought and saline-alkali (Jia and Wang, 2019; Sun et al., 2020). The high antioxidant tissues or organs of papaya can provide raw materials for natural antioxidants.

In addition, overall analysis of flowers and leaves of different cultivars demonstrated various antioxidant activities and diverse antioxidant functioning of flowers and leaves from the same cultivar. Multiple antioxidant activity and total phenolic content of several cultivars are mainly caused by the presence of different active compounds. More bioactive substances could be attributable to the highest antioxidant capacity for specific cultivars (Shahinuzzaman et al., 2020). The higher antioxidant activity in flowers compared to leaves of ‘Wild Zhongbai,’ ‘Zigeng,’ and ‘Zhongbai’ might imply that there was more synthesis and accumulation of bioactive compounds in flowers. Likewise, more antioxidant substances were accumulated in the leaves of ‘Daqing,’ ‘Qing No. 7,’ ‘Tainan No. 8,’ and ‘Zhongbai.’ The strongest antioxidant activity for both leaves and flowers was observed in the Daqing cultivar, indicating that it can be utilized as an important choice for the development of antioxidative by-products. The results of data analysis are consistent with those obtained from the TOPSIS method, which proves that the TOPSIS method is suitable in this context.

At present, there is no standard method for determining the antioxidant activity of natural medications and foods, and there are numerous methods for antioxidant capacity assay of natural products (Zhou et al., 2011) that can be employed to establish a detailed understanding of the antioxidant activity (Du et al., 2016). The antioxidant qualities of fruits are the result of the combined action of phenolic substances, which is an essential feature of phenols (Al-Najada and Mohamed, 2014; Mohamed et al., 2016). The DPPH radical scavenging activity among several vegetables and fruits can reflect the overall antioxidant content (Pyo et al., 2004), showing that the DPPH free radical scavenging activities of papaya extracts are correlated to their contents of antioxidant components. Through redox reactions, ABTS free radicals and Fe$^{3+}$ can change the color of the system, consequently, DPPH radical scavenging, ABTS radical scavenging and FRAP can depict the antioxidant capacity (Pang et al., 2018). The DPPH and ABTS assays investigate the antioxidant activity of experimental samples by tracking their reactions (including absorption and release of electrons), while the FRAP assay explores the antioxidant capacity by monitoring the changes in the reducing power laterally. The antioxidant capacity of samples can be understood comprehensively from three perspectives.

In this study, DPPH, ABTS and FRAP assays were conducted to compare and evaluate the antioxidant properties of different parts and cultivars of papaya. As our study shows, the results and data acquired by the three methods varied considerably. It was found that the numerical values of antioxidant activities in different parts of papaya using DPPH and ABTS assays were more consistent,
but the levels from the FRAP assay were higher. Despite this, the activity trends measured by the three methods were nearly identical. The activities in flowers of several cultivars manifested the same tendency from three assays, but the differences in most cultivars were not apparent. There were some discrepancies in the highest values of DPPH, FRAP and ABTS assays for leaves form different cultivars. However, it was clear that the top three rankings measured by each method were the same, as were the top three comprehensive evaluations.

From a certain perspective, the activities assayed by DPPH, ABTS and FRAP methods as well as total phenolics, and total flavonoids all have a definite correlation. It was shown that DPPH and ABTS scavenging activities possessed a substantial positive correlation ($r = 0.9540$). This also started that for determining the antioxidant activity of different parts of papaya, either DPPH and ABTS might be used, and then compared with other methods for simultaneous evaluation. Besides, DPPH or ABTS also manifested a stronger correlation with total phenolics and total flavonoids (all reached more than 0.90), indicating that phenols and flavonoids make a significant contribution to the antioxidant capacity of papaya fruit (Chen et al., 2020; Jiang et al., 2020; Niu et al., 2020) of papaya fruit. In contrast, compared to phenols, FRAP showed a more significant correlation ($r = 0.9207$) with total flavonoids. There was also an obvious correlation ($r = 0.9372$) between total phenols and total flavonoids, indicating that total flavonoids made a great contribution to the antioxidant capacity of total phenols, which is consistent with Jia et al. (2019). Total phenols and total flavonoids accounted for a high proportion of the contribution of papaya antioxidant capacity, and the results obtained by DPPH and ABTS in the determination of papaya antioxidant activity showed strong similarities, thus, the combination of these two methods and the FRAP assay might lead to more accurate and comprehensive experiment conclusions.

Conclusion

In this study, comparisons were made between tissues of different organs of several cultivars in order to investigate and assess the antioxidant properties of *Carica papaya*. The strongest antioxidant activities were found in the leaves of papaya fruits, with the roots showing the next highest levels of activity. The leaves of the ‘Daqing’ exhibited the strongest antioxidant activity, while the flowers of the ‘Wild Zhongbai’ manifested the highest antioxidant capacity of all evaluated fruits. The antioxidant capacity and antioxidant components of papaya, as well as its applicability in other disciplines such as medicine and health are worthy of exploration. Further research into the antioxidant utilization of papaya is still needed.

Disclosure Statement

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