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Review

Effect of pruning on carbohydrate dynamics of herbal and medicinal plant species: Prospects leading to research on the influence of pruning on productivity and biochemical composition of bush tea (*Athrixia phylicoides* D.C.)

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Pruning is an essential agronomic practice and it has been shown to be the most important operation, next to plucking, which directly determines the productivity and quality of tea bushes. In tea, pruning helps stimulate vegetative growth and prevent reproductive growth phase. In addition, pruning leads to enhanced branching and hence it rejuvenates the tea plants resulting in a greater number of tender leaves for healthier and better quality tea plants. This review illustrates the effects of pruning on yield and quality of herbal teas. Through the review, it is worthy investigating the effect of pruning and pruning time on yield and chemical compositions. It will also shed light on the effects of resting period before pruning. Lastly the review focuses on the effect of different pruning intervals on productivity of tea.

Key words: Carbohydrate dynamics, bush tea, productivity, pruning, quality.

INTRODUCTION

Athrixia phylicoides DC. belongs to the Asteraceae family and is commonly known as bush tea or bushman's tea. Botanically, bush tea is an attractive, aromatic, perennial, leafy shrub of up to 1 m in height with woolly white stems (Fox and Young, 1982). Leaves are simple, alternate, linear to broadly lanceolate, dark-green, glossy or shiny above and woolly white below (Roberts, 1990; van Wyk et al., 2009), with margins entirely or slightly revolute (Mudau et al., 2007a). The inflorescence head is sessible or subsessible and terminates auxillarily in large subcorymbose panicles. Flowers are daisy-like, with pink to purple petals and bright yellow centres (Van Wyk and Gericke, 2000). The fruits of bush tea consist of narrow, cylindrical and thin achenes that are approximately 0.01 to 0.06 mm wide. The seed is 4 mm in length and has 2 pappuses which act as parachutes during seed

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dissemination (Araya, 2005).

Bush tea has been used for many decades as a health tea and medicinal beverage in South Africa (Maudu, 2010; Rampedi, 2010) by different ethnic groups, which are Vha-Venda, Zulu, Lobedu, Southern Sotho and the Xhosa (Roberts, 1990; van Wyk et al., 2009). It is believed to have aphrodisiac, diuretic, laxative and anti-helmintic properties. It has been used by many generations to treat a wide range of ailments such as headaches, high blood pressure, diabetes, heart disease (Rampedi and Olivier, 2005; Rampedi, 2010), vomiting, and for washing and as a lotion on boils or skin eruptions (Roberts, 1990; Mudau et al., 2007b). It is also used as a cough remedy, and a purgative, blood purifier and the relief of sore feet (Olivier and Rampedi, 2008).

It has been shown that bush tea leaves contain 5-hydroxy-6,7,8,3',4',5'-hexamethoxy flavon-3-ol which is considered to be a new flavonoid, 3-0-demethyldigicitrin, 5,6,7,8,3',4'-hexamethoxyflavone and quecertin, total polyphenols, tannins and total antioxidants (Mashimbye et al., 2006; Rampedi and Olivier, 2008; Padayachee, 2011; Nchabeleng et al., 2012), which are major quality parameters for medicinal tea. Pharmacological evaluation of leaf extracts confirmed that the plant has anti-inflammatory, anti-hypertensive, narcotic and analgesic properties (Moller et al., 2006). The fact that *A. phylicoides* has high contents of polyphenols, lacks caffeine and cytotoxic effects, demonstrates its commercial development potential as a health beverage (Rampedi and Olivier, 2005; Joubert et al., 2008). van Wyk and Gericke (2000) and Mudau et al. (2007a) reported the suitability of bush tea for domestication and development as a commercial health beverage. However, the success of domestication and commercialization of bush tea hinges on maintenance and/or enhancement of quality of bush tea as a herbal beverage.

Research reports by Mudau et al. (2007b) reveals that herbal tea quality is one of the critical factors in commercialization that would determine the price of tea for sale and export. Cultural practices, is one of the factors that has been shown to significantly influence growth, yield and quality of herbal teas (Owour et al., 1990, 2000; Venkatesh et al., 2007). Pruning is an important cultural practice that has been shown to enhance both productivity and quality of *Camellia sinensis*. A study by Yilmaz et al. (2004) has shown that pruning affected the composition of tea leaves which determines quality. This finding is consistent with prior work by TRIT (2006) and recent studies by Tockclai (2008). Based on their studies they concluded that pruning is an essential agronomic practice and it is the most important operation, next to plucking, which directly determines the productivity and quality of tea bushes.

Pruning removes substantial amounts of leaves and branches which result in a drastic reduction in photosynthesis. Barua (1960) has showed that the peak photosynthetic efficiency of maintenance leaf remained for six months, then gradually declined and drops off due to senescence after 12 to 18 months. Barbora (1994) pointed out the need to replenish and maintain foliage for better yield and crop distribution. Plants have a functional equilibrium between their above ground parts (leaves) and below ground parts (roots) (Zeing, 2003). If plants are pruned the starch reserves in the roots are utilised for shoot growth to maintain the equilibrium. The speed of recovery from pruning of a tea bush depends on the plant's starch reserves in the roots (Ndunguru, 2004).

The main objective of this paper is to review the effect of pruning on productivity of tea bushes. More specifically, the review aims to investigate the relationship between leaf growth and root carbohydrate reserves after pruning; investigate the effect of aging of the pruning cycle on productivity and variation in concentration of secondary metabolites (which determines aroma, colour, and taste) with time from pruning. The review also will investigate the change in growth and productivity from skiffing as a method to prolong the pruning cycle and improve yield and again evaluate the effect of pruning and time from pruning on biochemical and quality parameters of bush tea.

This foundation will also assist in determining the role of pruning on yield, chemical composition and bioactivity of herbal teas. Understanding these functions can lead to proper agronomic practices to assess commercial viability of bush tea growth on large commercial scale in a well established orchard.

IMPORTANCE OF PRUNING IN MEDICINAL AND HERBAL PLANTS

Tockclai (2008) and TRIT (2006) provides insights into the importance of pruning as an agronomic practices and it has been shown to be the most important operation, next to plucking, which directly determines the productivity and quality of tea bushes. In tea, pruning helps stimulate vegetative growth and prevent reproductive growth phase. Ravichandran (2004) and Yilmaz et al. (2004) have shown that pruning leads to enhanced branching and hence it rejuvenates the tea plants resulting in a greater number of tender leaves for healthier and better quality tea plants. Satyanarayana et al., (1994) also reported that pruning leads to enhanced branching and hence a greater number of tender leaves. Tea plants are pruned to obtain a given table form and height thereby maintaining tea bushes in a manageable condition for plucking and to eliminate unnecessary and diseased branches (Ravichandran, 2004). In some areas pruning may also help to protect the plants from moisture stress. Tockclai (2008) pointed out that one of the main objectives of pruning is to divert stored energy to production of growing shoots. Although a lot of research has been carried out on the effect of pruning on productivity and chemical composition of black tea, little is known about its effect on bush tea.

CARBOHYDRATE DYNAMICS IN MEDICINAL PLANTS

A. phylicoides has been shown to contain different phenolic acid and flavonoid components (Mashimbye et al., 2006; Maudu, 2010; Maudu et al., 2010; Padayachee, 2011). Currently, the effect of dietary phenolics is of great interest due to their antioxidative and possible anticarcinogenic activities (Moller et al., 2006). Phenolic acids and flavonoids also function as reducing agents, free radical scavengers and quenchers of singlet oxygen formation.

In plants, carbohydrates in excess of growth requirements are used to synthesise carbon based secondary metabolites (CBSM) (Haukioja et al., 1998). According to the carbon-nutrient balance hypothesis, carbohydrates accumulated in excess of growth requirements will be allocated to carbon-based secondary metabolism, but does not explain how this carbon is distributed among different pathways and compounds. Nen et al. (1999) is of the opinion that different branches of the biosynthetic pathway of phenolic compounds may compete for substrates, and such internal metabolic trade-offs may explain the differential accumulation of the compounds. Studies done have shown the effect of pruning on total polyphenols and non structural carbohydrate but did not show how the carbon is distributed among different pathways and compounds. Moreover, the concentration of one compound may increase at the expense of another; thus, changes in the amounts of individual compounds are not necessarily correlated with overall changes in total secondary metabolism (Herms and Mattson, 1992). Reichardt et al. (1991) challenges the above theory and suggests that increased concentrations of secondary chemicals may, in some cases, be masked by rapid metabolic turnover. Against this background, there is need to investigate how CBSM are allocated to different pathways and compounds in leaves and roots in response to pruning and also to assess the patterns of concentration of primary and secondary metabolites in response to pruning.

EFFECT OF LUNG PRUNING ON BUSH RECOVERY AND YIELD

Through continued photosynthesis on the lungs, starch reserves are accumulated which help the tea bush to recover after pruning (Bore, 2001; Bore et al., 2003). However for it to be effective, lungs should be left on the bushes until the pruned portions have fully recovered. In contrast, Nwaka (1997) argues that lungs may direct some reserves for their own use and this may retard recovery of the tea bushes after pruning. It is therefore crucial to ensure that lungs are removed at an optimum time when they have helped the bush to recover but before they start retarding regrowth of the bushes.

The lung branches may continue to be plucked and would therefore help to sustain cropping before the pruned bush recover. In studies carried out in Kenya, Sri Lanka and north east India, it was found that tea yields increase in the year of prune when lungs were retained on the bushes until tipping-in time (TRI, 2001). The size of lung branches greatly contributed to the overall yield, with yield in the pruned year increasing with lung size. However, variations on the size of lungs left on the bushes, their contribution to yield has varied from non-significant to significant. In studies where lungs have been plucked, it has been shown that retaining lungs beyond tipping -in time would lead to yield reduction, probably because of retarding effects on regrowth (Mphangwe, 2012). Although a lot of research has been done on the effect of lung pruning on bush recovery and yield of *Camellia sinensis*, no research has been done in bush tea. Thus there is need for researchers to investigate the effect of lung pruning on bush tea recovery and yield after pruning.

EFFECT OF PRUNING LEVEL ON PRODUCTIVITY

Studies conducted in Sri Lanka by on the effect of different pruning levels, revealed that top pruning significantly increased the number of plucking points, fresh and dry weight of leaves. All the four pruning levels did not significantly affect the growth rate. However results revealed that top pruning was found to be the best among the remaining different pruning levels. Down-pruning caused more plant deaths and reduced subsequent yields (Magambo, 1980). The same results were observed by Maudu et al. (2010) who concluded that basal pruning is not viable in bush tea because the treatment showed highly reduced growth.

EFFECT OF PRUNING ON QUALITY

It had been demonstrated that variation in growth rate is expected to cause some changes in the green leaf constituents and hence the quality of made tea. Similarly, later research demonstrated that the quality of black tea improves with time from pruning. Thus, according to Ravichandran (2004) pruning as such leads to adverse effects on tea quality. Although a lot has been done on the effect of pruning height in *Camellia sinensis*, little has been done on the effect of pruning bush tea on productivity. Studies by Maudu et al. (2010) on the effect of pruning height on growth (yield) and quality (chemical composition) of bush tea showed that pruning reduced yields and quality. The results also showed that pruning at different heights have no favourable effect on quality of bush tea. Total polyphenols remained higher in unpruned tea plants, no significant differences were observed in tannin and total antioxidant content in pruned tea at

different heights. Unpruned tea plants remained the tallest plants, with higher number of branches, bigger leaf area and larger biomass than pruned tea at different heights. Research including that of Yilmaz et al. (2004), reported the same trend of less yields in the first year, with yields increasing in the subsequent second and third years. It has also been shown that during the first year of the pruning cycle, yields are generally low, because bushes have to recover from the prune before plucking can resume and because it takes time for shoot numbers to build up (TRIT, 2006). It is recommended that there is need to investigate the impact of pruning bush tea in the long run stretching over two and or more years to allow for accumulation of starch reserves in stems and roots. Mudau and Mariga (2012) pointed out that pruning has a direct effect on regrowth and recommended that it should be tried at field scale on cultivated bush tea to assess the vigour of growth, productivity and quality.

EFFECT OF AGING OF THE PRUNING CYCLE ON PRODUCTIVITY OF TEA

In the first year of the pruning cycle, yields are generally low, because bushes have to recover from the prune before plucking can resume. It takes time for shoot numbers to build up and a ground cover to be established. As the cycle progresses, shoot numbers build up, average shoot size and weight diminish and growth rates slow down (TRIT, 2006). The net effect is that 2nd year yields tend to be the highest, with the crop falling away in subsequent years (Satyanarayana and Sharma, 2004). Prior studies by Barua (1989) are consistent with the above observation and showed that productivity in *C. sinensis* decreases 2 to 3 years after pruning. However, the length of, and productivity during, the pruning cycle, vary greatly among tea varieties, and environmental and management conditions (Mphangwe, 2012).

Yilmaz et al. (2004) observed that polyphenol contents, which are one of the most significant quality traits of tea, gradually declined until the pruning age of 5. Tea yields started to decrease after four harvest years following pruning. Therefore, after 3rd or 4th year of pruning yield starts to gradually decline and this leads to another pruning operation (Satyanarayana and Sharma, 2004). Skiffing is normally light pruning and involves removal of the green wood at about 15 cm above the pruning height and has been found to prolong the pruning cycle in Sri Lanka (Nissanka et al., 2004). Light skiffing at the 5th year after pruning has been shown to enhance productivity by 42%.The effect of age after pruning on productivity and possible ways to prolong the pruning cycle has not been studied in *A. phylicoides*. Therefore, there is need to investigate the impact of aging of the pruning cycle on physiological and yield parameters and investigate the change in growth and productivity from skiffing as a means of prolonging the pruning cycle.

EFFECTS OF PRUNING TIME ON TEA REGROWTH

The time at which pruning is done is important in determining regrowth and performance of tea (Mphangwe, 2012). A lot of research has been done in an attempt to find the best time of pruning for maximum regrowth and these attempts have yielded varying results that could be attributed to complex factors prevailing during pruning time (Mphangwe, 2012). However, no work has been done on the effect of pruning time on tea regrowth and productivity.

Root starch reserves play an important role in recovery of tea after pruning (Wijeratne et al., 2002). The speed of recovery from pruning of a bush depends on plant's starch reserves in the roots (TRIT, 2006). The more starch reserves there are, the faster will be the recovery from the prune. Potassium deficiency, in particular, has been shown to have a very marked effect on recovery.

A study was conducted in Sri Lanka to monitor the variation of root reserves in relation to yield over a 3-year pruning cycle of *Camellia sinensis* and to assess the influence of root reserves on recovery after pruning (Wijeratne et al., 2002).Three periods of resting before pruning (0, 1 and 2 months) were tested on tea clones. The results showed that those 1 to 2 months of resting before pruning increased root reserves. The level of root reserves declined rapidly soon after pruning. The replenishment of root reserves commenced only after two months from pruning and complete replenishment of root reserves occurred about 10 months after pruning. Further analysis of results showed a clear positive relationship between the level of root reserves at pruning and the degree of recovery following pruning. This finding shows that, to sustain the productivity of tea bushes, the importance of building up of adequate root reserves before pruning of tea is emphasized.

Studies done by Baktir (1987) on the effect of pruning ages (1, 2, 3 and 4 years) on root starch content and production of seedling tea have shown that the older the pruning age, the higher the starch content. Maximum starch content of 15.30% was reached 3 years after pruning and at the pruning age of 4 years starch content decreased to 13.58. Hence, a combined reduction of both sink strength and source capacity during the fourth year could have brought the significant reduction in tea yields. It is recommended that pruning should be done when carbohydrate reserves are not limiting. No work has been done on the effect of resting period and pruning time on quality and yield of bush tea. There is need to investigate the relationship between leaf growth and root carbohydrate reserves after pruning. Carbohydrate reserves are utilised in times of adverse seasonal conditions. The timing, amount and location of their deposits should be investigated as a possible indicator to predict vigour and yield (Bore et al., 2003). Pruning should be done when the root reserves are high. Pruning and or tipping have been shown to check root growth and development. Carbohydrate reserves are enhanced by

agronomic practices.

EFFECTS OF RESTING PERIOD BEFORE PRUNING ON PRODUCTIVITY

Studies conducted by Watson and Gunasereka (1986) in Sri Lanka, showed that resting period had a significant effect only on regrowth at pruning. Resting tea bushes for 11 months before pruning lowered yields compared to resting tea for eight months; moreover, the unrested control had the highest yields, and hence, no advantage of resting period was observed (Watson and Gunasereka, 1986). This result indicates that more dry matter accumulated during the resting period and that resting period before pruning might have an effect on replenishment of carbohydrates used in regrowth of tea after pruning (Bore, 2001). On the contrary, bushes that were plucked continuously had better bud-breaks. This finding is consistent with prior observation by Wadasinghe and Gunasereka (1986) who observed an increase in carbohydrate concentration with increased resting period. However, no significant effect of resting period on yields was obtained in the 1997 pruning cycle. Bore et al. (2003) claim that the above observation is due to the ``carry-over'' effect. Based on the aforementioned discussion, it is hypothesised that, treatment effects may not be realised within the year of experimentation, but may be carried into subsequent years.

CONCLUSIONS

It is evident from the above discussion that extensive academic research has been explored on the effects of pruning on productivity and quality in tea. However, little has been done in bush tea. The effect of phenolics and flavonoids is of great interest due to their antioxidative activities, possible as anticarcinogenic reducing agents, free radical scavengers and quenchers of singlet oxygen formation. Therefore, there is need to carry out extensive research to address the fore mentioned objectives in bush tea. Knowledge of the importance of pruning and its effects on productivity and quality of *A. phylicoides* is necessary for future research which will lead to proper agronomic practices for the commercialization of bush tea. With the increasing demand for herbal teas worldwide, South African bush tea can be an important shrub to supply herbal tea.

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