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EFFECT OF PHENOLIC COMPOUNDS ON THE FLAMMABILITY IN FOREST FIRES

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ABSTRACT
Forest fires are one of the key factors that play a significant role influencing and shaping the forest ecosystems. In a natural ecosystem where the fire took place, it is known that many plant species demonstrate various adaptations at the point of survival or self-renewal after the fire. A number of hypotheses put forward that a direct impact of fire severities and the ignition time of fire on the plant (fuel characteristics) combustibility is associated with physical properties of plants. However, prior studies that prove a relationship between flammable properties of plants and survival of the plants after fires are quite insufficient. In this review paper, the relationship between fire and phenolic compounds that have an effect on the flammability, and the relationship between flame geometry and the ignition time of the chemical components in forest fire were examined.
KEYWORDS: Forest Fires, Flammability, Phenolic Compounds

INTRODUCTION
Forest fires are one of the key factors that play a significant role influencing and shaping the forest ecosystems. In a natural ecosystem where the fire took place, it is known that many plant species demonstrate various adaptations at the point of survival or self-renewal after the fire. These adaptations, shown by plants, are evidence that the adaptive properties found in the structures vary with the end of the fire (1).
Despite the fact that the majority of forest fires are human-origin, the research of the causes of natural fires is very important in terms of minimizing the negativity caused by the fire. For this reason, many researchers have focused on different subjects. These subjects can be defined as fire regimes, differences plant flammability and it is related to the morphology of leaves (2), crown structure (3), floristic design (4), lignin (5), the types of germination (6), water (7), (8), carbohydrate (9), mineral (10) which are chemical components of the plants.
The composition of plant communities and fire regimes are directly related to each other in the ecosystems where natural fire dynamics are observed (11). When considering the frequency (frequency) and spread of forest fires; vegetation characteristics, seasonal variations, as well as amounts of flammable substances and their effects on the formation of fire, play an important role in determining fire behavior (12), (13), (14). The amount of fuels in forest areas varies according to the diversity and distribution of species in the ecosystems and general characteristics of species in the fields where they grow (15), (16). A number of hypotheses put forward that a direct impact of fire severities and the ignition time of fire on the plant (fuel characteristics) combustibility is associated with physical properties of plants. However, prior studies that prove a relationship between flammable properties of plants and survival of the plants after fires are quite insufficient. In this review paper, the relationship between fire and phenolic compounds that have an effect on the flammability, and the relationship between flame geometry and the ignition time of the chemical components in forest fire were examined.

FIRE EFFECTS ON ECOSYSTEMS
Fires cause significant amounts of biomass loss every year in many ecosystems, from savannah grasslands to tropical meadows to northern forests, but also cause biomass growth because they allow the renewal and development of vegetation at the same time. Through fire, some ecosystems change their structure through fire which that ensures the regeneration and continuity of ecosystems (17), (18). Many plant species have developed

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different adaptations to survive and regenerate after fire (1). The ecosystems formed by coniferous trees are very sensitive to fire while the ecosystems formed by deciduous trees are not equally sensitive.

Fires are very important in Mediterranean ecosystems, and its effects on the ecosystems depend on their severity and frequency. The occurrence of a fire depends on both the meteorological conditions and the properties of fuels. In the same type of vegetations, the self-renewal of vegetations is slow following frequent fires, and recurrent fire events have a negative impact on the point of self-renewal of the vegetation (19), (20), (21), (22).

GENERAL CHARACTERISTICS OF FLAMMABLE MATERIALS AND THE RELATION OF FLAMMABLE MATERIALS TO FIRE

The result of the development of forest areas; annual plant material and woody plant species constitute flammable substances. Flammable materials are defined as substances and compounds which are flammable and prone to ignition, that can be found in and outside the soil. Annual plant material and woody plant species resulting from the development of forest areas constitute flammable substances. Flammable materials are indicated as substances and compounds with flammability which are likely to be found in and out of the soil (23), (24). The vegetations which are formed by highly structured perennial plants, annual plants and herbs all constitute forest fuels. Forest fuels have an significant role in the initiation and spreading of the fire. For this reason, the categorization of fuel types by forest areas has a crucial role in fire management when examined both in terms of conservation biology and biodiversity (25). The forest fuels deposited on the surface are very important at the point of spreading the fire (26), (27), (28). There are many studies in which the influences of distinct fuel variables on flammability are tested. The most commonly used parameters are moisture and density (29), (30), (31), the sort of vegetation (32), (33), (34), (35) , (36) the amount of terpene (37). The moisture and water retention capacity of the flammable materials are one of the most important parameters affecting the behavior of the fire after it emerges. Not only the meteorological conditions but also the flammability of the vegetation are effective for the formation of the fire, and the water holding capacity of the leaves is directly related to the flammability (38), (7), (39), (40). Trabaud (1976) indicated that leaves which contain small amount of water show more flammability than the species that contain a high amount of water. Although this is the case for many plant species, studies with *Quercus pubescens* have shown that this plant has quickly flared up when it has high water content. Surroundings elements, the history of life and ecophysiology of the plants are associated with the water holding capacity as well as the flammability (7).

It has been found that some plant species have the same amount of water but more flammable than others (40). Different types of vegetation contain various types of fuels in their structure (41), (42), (43), (44), (45). The accumulation of thin branches of trees on the surface to form a dead surface directly affects the amount of volatile oil, one of the parameters affecting the flammability of the fuel (43), (45).

In addition to the amount of moisture which is found in the pond, Volatile organic compounds such as monoterpenes are another factors that affect flammability. The VOC’s are found in many Mediterranean plant species. Plants with these VOC’s have the ability to burn easily (46). However, the effect of these organic compounds on flammability is still being discussed (39). White (1994) found that flammability shows a positive correlation with the amount of monoterpene (47). Owens et al. (1998) supported White's outcomes in their work (48). It is known that many plants in the Mediterranean basin have emitted volatile terpenes. These plants, which are capable of spreading terpenes, are thought to have special structures that allow the VOC’s to diffuse through the storage area (49), (50), (51), (52). Plants that do not have these storage sites have the ability to form and emit VOC’s at the same time. According to White (1994), the leaves containing VOC’s have significant effects on flammability (47). Alessio et al. (2008) revealed the flammability properties of different plant species, and investigated that *P. halepensis* demonstrates more flammability than *E. multiflora*. In the same study, it was discovered that *E. multiflora* has no specialized forms to store VOC’s, although *P. halepensis* has resinous vesicles in its leaves to contain VOC’s. This difference reveals that there are more tendency of fire for plant species with high volatile organic compounds and how these plants easily catch fire (53).

In ecosystems with natural fire regimes, there is an interactive relationship between plant communities’ composition and fire regimes. Plant species in the ecosystem have an important role in the change of fire regimes, which directly affect the properties of the flammable materials (4), (54). Any change in flammable materials can alter fire behavior, plant composition, ecosystem structure and long-term fire regime (4).

FACTORS AFFECTING FLAMMABILITY

Flammability is expressed by the ability of the flammable material to ignite during the fire, and is represented by four components: ignitability, sustinability, combustibility, consumability. While ignition is expressed the time which is from the first period of time that the material is to be exposed to the ignition source until it ignites,

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sustainability is defined as the process that takes place until the material is completely burned regardless of the ignition source. Flammability is directly related to the physical and chemical properties of the fuel, and is a concept that expresses the intensity and the speed of combustion of the material (55). The term of consumability is defined as the amount of substance consumed during combustion (56). Factors such as the amount of moisture, the percentage of carbon components (cellulose, hemicellulose, lignin) (57), (58), volatile compounds (59), (58), (44), (48), mineral content (10), leaf mass (2), etc. possessed by the flammable substances which are factors that directly affect the flammability (60). Although each of these characters can be analyzed using different methods at different sizes, the effects on both plant flammability and their relationship to each other are not fully understood (59), (61), (62). Plant flammability between different species has been extensively explored in very few studies. In a study conducted in the United States involving six plant species, it was determined that dry mass was consumed by the heat generated. Researchers reported that leaf biomass and humidity contribute the further amount of heat the plant produces than other characters (62). Behm et al. (2004) examined the biomass and leaf properties that are effective on components such as ignition, sustainable combustion, sustainability and consumability (63). As a result of the study, it was observed that the flammability varies between different species. However, the flammability of each species is different due to different reasons, and it has been found that the species have different combustibility properties even they are within the same genus.

PHENOLIC COMPOUNDS

Phenolic compounds are a generic name given to compounds containing one or more hydroxyl groups directly attached to an aromatic ring, and they form plant secondary metabolites with alkaloids and terpenoids. These compounds form a large group of molecules with different functions that play a role in the growth, development and defense mechanisms of plants. Lignin, tannin, terpene and flavonoids are the most important phenolic compounds. Recent studies have shown that these compounds have a crucial effect in the formation of a fire and their influences on flammability are being investigated (39).

EMISSION TYPES IN PLANTS

The plants can emit many VOC's such as mono and sesquiterpenes, alcohols, isoprene and carbonyls. Compounds such as terpenes in the terpenoid class have the necessary volatility to exhibit their emission. Mono and sesquiterpenes are usually collected in specialized structures found in plants once isoprene is produced. Sanadze (1991), Sharkey et al., (1991) and Monson et al. (1991) have developed a number of perspectives on isoprene synthesis and emission (64), (65), (66). Isoprene synthesis begins in chloroplasts, and production occurs only in the presence of light. It is closely related to photosynthetic action. In addition to the existence of light, isoprene emission occurs in a high temperature environment. More than two hundred woody plant species have been found to be capable of isoprene emission (64). Tropical forests are the most important occurrences contributing to worldwide emissions of isoprene. According to the findings obtained, the global isoprene emission is the sum of the total monoterpen and sesquiterpenone emissions (68), (69). Several studies have shown that non-terpene volatile compounds constitute a large proportion of non-methane hydrocarbons (NMHC) in plants. (70) have identified the emission rates of hydrocarbons in more than thirty plant species. (71) considers that the non-terpene compounds worldwide are about half of the terpene emissions.

Terpenes are synthesized by plants with more than 15,000 known types (72). Some plant species in the Mediterranean region generate and release high bulk of volatile terpenes from different mixtures. Some plant species, such as *Quercus ilex* (73) and *Quercus coccifera*, release directly after synthesizing the terpene, while *Rosmarinus officinalis* L. (74), *Cistus albidus* L. and *Pinus halepensis* Mill. (46) are stored as organic compounds before the release of terpenes. If a plant has reserves of terpenes such as glands and resin channels in its thorns, the release of terpene does not depend on its amount and composition (75), (76), (50).

When it is considered that there is a small number of relationships between stored and emitted compounds, the rate of diffusion of organic compounds depends not only on the amount in the reservoir that is stored but also on the volatility properties of the temperature (77). Terpenes has also a significant role in the defense and survival of plants in the ecosystem against biotic (herbivores and pathogens) and abiotic factors (78), (79). Terpenes also regulate competition between competing plants (80). However, only a few studies have shown that the secondary metabolites of carbon build-ups depend on environmental factors in the competition of plants with each other. Competition among plants is the most important environmental factor, especially in Mediterranean ecosystems (81).When the plant begins to compete for soil resources, growth, rate of photosynthesis and nitrogen content start to degrease (82), (83), (84). Any differences in these parameters lead to a change in the terpene release of the plant (85), (86), (87). Although many studies have been conducted, it has not been revealed how the competition factor has an effect on terpene storage and release in plants. Only one study

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identifies terpene release routes in plants under different competitive conditions (88). When the effect of environmental factors is examined, the difference in the amount of terpen available on the leaves can be explained in two ways. Firstly, if the terpenes have a low boiling point, the increase in terpene concentration in the leaves can lead to an increase in leaf flammability and fire risk (48), (89). This is very common in plant species (*R. officinalis* ve *P. halepensis*) in Mediterranean ecosystems where fires occur frequently, and the climate supports high terpene storage. Secondariliy, the emissions of biogenic terpene play an important role in the emergence of secondary pollutants such as ozone (90) and sprays (91) in the troposphere.

Monoterpenes and sesquiterpenes are found at moderate levels in phytohormones, phytosterols and carotenoids of high-build plants (92), but they are stored in specialized plants in only 50 families (93). In order to determine the emission rate of organic compounds, the metabolic pathways required for their secretion and storage in plants must be well known. The essential oil-releasing organs are found in the resinous channels in the leaves and shells of conifers. Although resin is considered a non-volatile product in plants (94), it has similar essential oils in its content. The compounds found in the resinous channels of the Coniferae (Araucaria, Pinus, Picea, Abies, Larix, Tsuga, Taxodium, Cupressus, Thuja, Chamaecyparis, Juniperus) and Anacardiaceae (Pistacia, Cotinus, Rhus) species are called oleoresin (pine resin, oil resin). The volatile oil in the leaves and bark of the pine species cause these parts to burn completely during the fires. The presence of extractives in these parts of the plant promotes the rapid and easy burning of the plant. Members of the Cistaceae family include compounds called aromatic resins in external glands. Chemical substances-containing glands of fluffs found in plants are known as the source of essential oils, and these are common in Lamiaceae (Salvia, Rosmarinus, Majorana, Satureja, Lavandula, Thymus Melissa, Mentha), Cannabaceae (Humulus, Cannabis), Solanaceae (Lycopersicon), Geraniaceae (Geranium, Pelargonium), Juglandaceae (Juglans), and Myricaceae (Myrica) families. Essential oils deposited in internal structures are found in structures consisting of isolated cells called idioblasts where specialized cells or secretions, pigments, minerals and products are stored. These structures are found in various regions in different species. For example, these structures are found in the leaves of Laurus and Magnolia species, in the rhizomes of Acarus and Zingiber species, and in the bark of Cinnamomum species. Even under the same conditions; the exhibition of different burning characteristics of these plants, which form some of the maquis elements led to the fact that the extractives of the flammable substances play an important role as well as the physical location of flammable materials (95).

FACTORS CONTROLLING THE EMISSION OF VOLATILE TERPENES

The compound of volatile terpenes in the plant is also affected by environmental factors when genetically controlled. The composition of monoterpenes is used in chemotaxonomic studies to distinguish and illustrate the origins of the different ecotypes of *Pinus halepensis* (96) or *Pinus nigra* (97) species. The lipids accumulate just below the leaf upper membrane, and are continuously released from the pores or directly from the cuticle. As observed in diverse Lamiaceae species, the cuticle is expanded by increasing the amount of lipid (98). If the VOC's are stored in internal structures such as in the Pinaceae species, oscillations occur via stomata which has little effect on the emission rate of the conductivity.

Monoterpenes are released from the resin channels and penetrate through epithelial cells. The metabolic pathway has high resistance because the epithelial cells in the Pinus genus have a suberized waxy structure (94). In the Banthorpe's study, he proposed a hypothesis that there were two different terpen pools. The first one is quite sensitive to external influences while the second one is constant. The size of the terpen pool varies in different species under different conditions. Control of monoterpene production differs from control of terpenoid emissions because some volatile monoterpenes are synthesized in leaf inner tissues (mesophyll), and directly permeate through intercellular air spaces (99). For the size of the terpen pool that the plants contain, the control of the emission rate of volatile terpenes is ensured by stimulation of the compounds at the vapor pressure temperature, where the compounds are sensitive (100), (101). Tingey et al. (1991) analyzed different species of Pinus, and reveal that the pinene emission of bicyclic chemical compositions of monoterpenes is 1.2 to 3.2 times more than the expected vapor pressure alters with increasing temperature. Despite the fact that the vapor pressures of the compounds are directly related to the temperature of leaf, in different researches, only the temperature of air is estimated. This reveals many disagreements about the subject. When considered in its simplest form, the leaf temperature can be much higher than the air temperature, which means more emissions than expected. This situation facilitates ignition and combustion. In all cases, daily and seasonal deviations from vapor pressure are also influenced by other factors in controlling emissions (101).

THE IMPACT OF VOLATILE ORGANIC COMPOUNDS ON MEDITERRANEAN TYPE ECOSYSTEMS

The impact of VOC's on mediterranean-type ecosystems has been understood by studying the volatility of volatile oils, resins and volatiles in plants, according to different climate zones in semi-arid areas. Ross and Sombrero (1991) found that plant species grown in Mediterranean ecosystems account for 49% of the total volatile oil world production (102). Of the 153 plant species found in about 50 families, 90 have the essential oil storage feature in the Mediterranean ecosystem. The excess of volatile oils and resins produced by xerophyte in Mediterranean ecosystems can be understood by evaluating climatic and edaphic parameters together. Even under extreme conditions, plants separate 5% -40% of total carbon for use in the biosynthesis of essential oils. The association of essential oils with stress factors (high fire frequency, dry and hot summer, elevated leaf temperature, high radiation changes, insufficient nitrogenation areas, high herbivore pressure and high fire frequency) has been shown in several studies in the ecosystems of Mediterranean. The VOC's have developed different strategies for the Mediterranean climate compared to the climatic changes that took place in the terpene pool, which usually reaches its maximum in summer. These strategies are shaped by the climatic changes that take place in the terpene pool (102).

CONCLUSION

In addition to meteorological factors, the influence of fuel properties is extremely important in the initiation and the spread of forest fires. It is possible to come across a number of studies on the physical properties of fuels with many meteorological factors that are effective on ignition and combustion. Besides, some studies have shown that the chemical properties of the flammable material in the Mediterranean ecosystems are extremely effective on ignition and combustion. However, these studies seem to be inadequate. Determination of the amounts of terpenes, resins, volatile oils and other extractives according to species-based and plant parts (leaves, branches, bark, etc.) periodically appears in the regions where the plants are located. Each of these studies is required to be completed in each of the pine species and the maquis elements, especially in the case of flammable substances. Thus, in addition to the physical properties of the flammable material, its effects of the chemical properties on the flammability can be demonstrated in detail.

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