Kaolin-Based Particle Films and Coffee Production

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Climate change, such as increases in atmospheric air temperature, threatens Brazilian coffee production, which is mainly carried out on small rural properties in a family farming model. Increases in air temperature causes heat stress to the plants, resulting in physiological damage. The concept of environmentally sustainable coffee production is latent among coffee growers, who adopt practical actions to respect and preserve the environment during the production process. Increases in productivity are related to the adoption of technological innovations such as the use of PKPF in the management of plantations, being a viable alternative to increasing the plantation areas, and thus reducing native vegetation.

innovation climate change high temperatures agriculture

1. Climate Change and Coffee Production around the World

In the different phenological phases of coffee plants, environmental factors can have severe impacts, which can compromise productivity and beverage quality. A large number of management strategies in coffee growing systems exist, and they can be implemented to avoid the effects of adverse weather conditions on the productivity and quality. Among these management strategies are the use of rootstocks adapted to abiotic stress, the selection of more tolerant genotypes, the proper management of the canopy to optimize the source–drain relationship, the management of water and soil use, and the application of special protective compounds [1][2].

For the period 2019 to 2030, growth rates have been predicted to range from 1.5% to 2.5% per year. Based on Brazil's significant participation in the global commercialization of this commodity, the Brazilian Agricultural Research Corporation (EMBRAPA) elaborated three strategic scenarios related to the global demand for coffee beans. If we look at one of the scenarios, i.e., the scenario in which the demand growth rate is fixed at 2% per year, the nations of the planet will consume approximately 208.80 million 60-kg bags of coffee in 2030. In order for Brazil to continue in its position as the largest coffee producer/exporter, and thus the most reliable global supplier, in 2030 Brazilian production must mandatorily increase by 74 million 60-kg bags [3].

Regarding the effects of climate change, several genetic improvement initiatives have been employed with the aim of increasing the tolerance of coffee plants to higher temperatures. However, these demand high resources and a long time period due to the complexity of the genetic structure of the species [4]. Coffee tree improvement, under abiotic stress conditions, for several traits simultaneously is laborious, complex, and costly. Thus, even considering the breeding strategies, biotechnological tools, and irrigation systems for a productive performance under heat stress conditions, the adoption of new sustainable alternatives in the short term is fundamental [5][6].

In the context of sustainable alternatives, the application of processed kaolinite-based particle films (PKPF) onto the leaves and fruits of plants grown in full sunlight can help plants to tolerate abiotic and biotic stress [7]. The use of PKPF as a stress mitigation agent, in particular high atmospheric air temperatures and excess solar radiation, has been intensively studied [8]. The efficiency has been proven, as the white protective film forms a physical barrier on the surface of the leaves, reflecting the excess solar radiation, promoting the protection of the leaves and fruits against high temperatures. In the absence of this type of protection, the destruction of the leaf mesophyll may occur, with significant increases in the degradation of chlorophyll molecules [9]. The Marrakech Treaty, a result of discussions at the 22nd UN Climate Conference (COP22), reinforced the need for signatory countries to prioritize the implementation and acceleration of actions to reduce the rate of increase in global warming, and in this context Brazil plays a leading role in the preservation of natural ecosystems.

2. Brazilian Coffee Production in the Senario of Climate Adversity

The consolidation of Brazilian agribusiness, based on coffee farming, is strongly related to the negative effect of biotic and abiotic factors on this species [10]. The productivity, aroma, and flavor of coffee, as well as the intensity of pests and diseases, are related to variations in climate factors, particularly temperature and humidity [3]. The most suitable regions for growing high-quality and productive Arabica coffee are the mountainous regions, located at an altitude above 1200 m, with an average annual ambient temperature between 18 °C and 22 °C [11]. In Brazil, there are six coffee producing states, with Minas Gerais being the state with the highest production. This state accounts for more than 50% of the total coffee produced, and the coffee plants in Minas are grown over an area of more than 1 million ha. Thousands of farmers are employed in this activity [12].

In coffee plantations, studies on the impact of climate change indicate that the temperature is increasing by approximately 0.25 °C every decade. Concomitantly, in the periods of flowering and ripening of the beans, there has been a reduction in rainfall. This set of adverse weather events has caused a reduction in productivity of over 20%, particularly in the southeastern region, and especially in Minas Gerais [12]. Therefore, climate changes cause a reduced productivity and an increased economic and social vulnerability of coffee growers [13].

A study conducted at the experimental station of the Empresa Brasileira de Pesquisa Agropecuária de Minas Gerais (EPAMIG) [14] showed that the parts of the coffee plant exposed to excess solar radiation are compromised through damage to the photosynthetic machinery, resulting from the high degree of chlorophyll degradation [15]. Simultaneous to the reduction of the photosynthetic rate (photoinhibition), excess solar radiation raises the rates of transpiration, respiration, and photorespiration [8]. The degradation of chlorophyll molecules is observed through the presence of chlorotic spots, commonly known as “sunburn” or “scalds” [7].

Studies highlighting the sensitivity of coffee plants subjected to climatic adversity—specifically, instability in the rainfall and air temperature regime—have been carried out. Thus, more than 90% of the actual coffee plantations would be compromised if there is an increase of 6 °C in the current average air temperature [10]. There is evidence that climate change has already started and is already having a serious negative impact on coffee production and other crops of high commercial importance [16]. In 2014, the state of Minas Gerais, responsible for a quarter of the total production, experienced a period of severe drought, accompanied by high coffee prices, which motivated financial speculation [17].

Regarding the adverse effects of climate change on coffee plants, the physiological process and productivity of every coffee crop depend on the fertilization of flowers, fruiting, and the filling of the grains with water and photoassimilates. During the pre-flowering period, and also during the initial phase of coffee bean formation, the presence of low relative humidity and, simultaneously, temperatures between 20 °C and 23 °C can cause the dehydration of the initial floral buds, known as “floral abortion”, and the fall of the “suckers”. This phenomenon causes significant losses in coffee productivity [18].

3. The Use of PKPF in Commercial Agricultural Crops

Kaolin is a naturally occurring mineral, consisting of hydrated aluminum silicate, and the theoretical chemical composition is 39.50% aluminum oxide, 46.54% silicon dioxide, and 13.96% water. Naturally occurring kaolin has traces of undesirable metals, such as red iron oxide (Fe_2O_3), which must be removed to achieve high quality, and also titanium dioxide (TiO_2), which must be eliminated to ensure safe handling and meet industrial specifications [19].

Kaolin is a versatile mineral, used in the cosmetics industry, in latex paints, as catalysts for oil refining, ceramic manufacturing, toothpaste, medicinal product formulations, food additives, and agricultural crop protection [20]. One of the most important uses of this mineral is for the bleaching of paper in the cellulose industries. It is chemically inert, has a soft texture, a high hygroscopic capacity, and a wide pH range. This mineral, commonly found in white color, does not undergo dilatation, is non-abrasive, and has low thermal and electrical conductivities [21].

Processed kaolin (PKPF) can be used as an ecologically acceptable agent in the management of commercial crops, because it is a product of low environmental impact and non-toxic. Mixed with water, and then sprayed onto plants, after the evaporation of the water, it creates a film of microscopic mineral particles adhering to the surface of the plant, be it leaf, branch, or fruit. Once on the plant surface, PKPF functions as a reflector of excess solar radiation and reduces the supra-optimal temperature stress. It has been verified that PKPF reduces the appearance of leaf burns (chlorophyll degradation and leaf mesophyll destruction), optimizes CO_2 assimilation, and improves productivity and fruit quality [22][23].

With respect to agricultural crops, to be effective, PKPF should have some of the following characteristics: having neutral pH, particle diameters smaller than 2 µm, formulations that enable uniformity of spreading and the formation of a uniform film on the plant surface. It should be porous enough not to interfere with leaf gas exchanges; allow the transmission of photosynthetically active radiation (PAR) to the leaf mesophyll; and also reflect ultraviolet (UV) and infrared radiation [7][22][23].

A PKPF product aimed at the agricultural market in Brazil, “Surround® WP”, is commercially available, and its efficiency has been scientifically proven [13]. This commercial product is based on processed, purified, and formulated kaolin with characteristics suitable for agricultural use, which is under patent protection of Tessenderlo Kerley Inc. [24][25].

PKPF is classified as a non-hazardous, non-flammable, odorless agricultural agent that is free of any chemically synthetic ingredients. Therefore, given this set of characteristics, the PKPF is classified in Brazil as exempt from mandatory registration for commercialization, both by the Ministry of Agriculture, Livestock and Supply (MAPA), as well as by the National Health Surveillance Agency (ANVISA) and the Brazilian Institute of Environment and Renewable National Resources (IBAMA). These are the agencies which regulate all types of agricultural products in Brazil [26].

The parts of the plants exposed to full sunlight are protected after spraying the PKPF, when compared to plants without PKPF, with an average reduction of 4 °C, which reduced thermal stress, in addition to reducing the transpiration rate of the plants by up to 25% [1].

In olive trees it has been proven to increase the amount of oil extracted from harvested olives, as well as increase the oxidative stability and olive oil shelf life and reduce acidity [27][28].

In apple trees grown in New Zealand treated with kaolin, the fruits had less sunburn damage caused by excessive solar radiation on the leaves, and there was a 17% reduction in leaf temperature [29]. Similar results were observed in South Africa for apple trees that had been treated with PKPF, with fewer losses caused by leaf scald due to high solar radiation [30]. "Galaxy" apple trees grown in Turkey that received three PKPF spray applications had increased fruit quality and, even at postharvest, there was an increase in fruit mass, Brix, and titratable acidity [31].

In Chile, studies conducted with apple trees showed that PKPF sprayed on the trees three weeks before harvest reduced the surface temperature of the fruit by 1.5 °C and promoted a 70.1% increase in the photosynthetic carbon assimilation rate and a 61.3% increase in the stomatal conductance rate. This resulted in a 16% increase in productivity [32].

In the cultivation of vines intended for wine production, PKPF increased the concentrations of phenolic compounds in the berries, in addition to promoting an increase in anthocyanins and ascorbate and greater antioxidant capacity [33][34][35]. As an additional benefit, the wine produced was visually more attractive and better appreciated when compared to wine produced from plants which had not been treated with PKPF [36].

In *Punica granatum* pomegranate plants, grown in India and in full sunlight, a 47% reduction in the rate of scalding of the fruit and leaf epidermis was observed once the surfaces had been treated with PKPF. The fruits free of blemishes on the peel had a better quality rating than those normally commercialized, and therefore PKPF applications have been considered as the best method for improving pomegranate quality in Turkey, as they have reduced sun scorch by up to 47% [37]. This agronomic practice has been incorporated into organic and integrated production systems of various crops in order to mitigate the effects of high temperatures in orchards [36][38].

In Egypt, when considering commercial tomato cultivation, a reduction in leaf temperature by 1.1 °C was observed, and there was a significant reduction in scald symptoms in the tomatoes exposed to full sunlight. As a consequence, there was a reduction in losses and improved quality in the marketed produce [19].

In Italy, another study conducted with tomato plants showed that in the fruit in which the epidermis received PKPF application, the epidermis was free of sunburn spots, and the fruit was classified as of "superior quality". As such, fruits had a higher added commercial value, which resulted in the generation of an additional profit of up to €900 per cultivated hectare [39]. The additional benefit promoted by PKPF, was the repellent action to insects called sharpshooters (Hemiptera: Cicadellidae), which transmit the bacterium *Xylella fastidiosa*. This bacterium is responsible for causing a lethal disease in orange, mango, tangerine, lemon, apple, grape, and coffee orchards [40][41].

Recent studies conducted in Brazil have shown that spraying PKPF on orange plants contributes to repelling pests called psyllids, *Diaphorina citri*, by up to 80%. This pest, feared by many citrus growers, acts as a vector for the transmission of the bacteria that causes greening (Huanglongbing/HLB), one of the most destructive diseases, and with the power to decimate citrus orchards of all ages in Brazil and worldwide [42][43].

4. PKPF Efficiency in Coffee Crop Management in Brazil

Photosynthesis is a process of complex chemical reactions, which depends on both adequate photosynthetically active radiation (PAR) and optimal leaf temperature for maximum CO_2 assimilation [43]. Research conducted between the 1950s and 1970s had shown that coffee plants are sensitive to ambient temperature greater than 25 °C, with the photosynthesis process coming to a halt at 34 °C [44]. Commercial coffee crops grown in full sunlight, which received PKPF spraying, were evaluated under unfavorable weather conditions and proved that the plants were more productive when compared to plants without PKPF protection [45]. Coffee trees exposed to temperatures above 23 °C, without forest shading, tend to present a higher rate of flower abortion, inducing the plant to produce more leaves and fewer berries [7][46]. Research evaluating the effect of PKPF on the sensorial quality of the coffee beverage, conducted on the Catuaí Vermelho IAC-44 variety, showed that a plantation without PKPF treatment recorded 71.66 points, compared to 77.13 points obtained in the area where PKPF was sprayed onto the plants, an improvement of 9.2%. The biggest benefit of the increased sensory score was that the selling price of the coffee was 15.5% higher than the price of a 60-kg bag of the standard treatment coffee harvested by the farmer [47]. Another scientific study published by the same authors showed a 28.4% increase in grain quality and that each kg of grain-dried coffee beans with PKPF protection yielded 0.635 kg compared to 0.594 kg from the area harvested without application of this

product. Coffee plants protected with Surround® WP produced 94 60-kg bags per hectare, compared to 91 bags from plants without protection [48]. Studies of the protective capacity of PKPF for the leaves of young *C. arabica* and *C. canephora* coffee plants, transplanted from the nursery to the field, in full sunlight, over two seasons of the year (autumn and summer), demonstrated that PKPF had a protective effect on the leaves of both coffee species, keeping the leaves healthy, vigorous, and free of symptoms of sunburn, when compared to plants which had not treated with PKPF [7].

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