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Spray Deposition on Watermelon Crop in Aerial and Ground Application

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Abstract

The quality and quantity production of watermelon requires the effective control of pests, diseases, and weeds, which is directly related to spraying techniques. The method of application of phytosanitary products is essential, but, most of the time, emphasis is given mainly to the applied product and little attention to the application technique. The objective of the present study was to characterize the ejected spray in the aerial and terrestrial spraying of watermelon crops, with the use of adjuvants in a liquid solution. The experiment was carried out in two commercial plantations, in an entirely randomized design, employing a 6 × 2 factorial scheme, with six forms of application and two liquid compositions. The droplet spectrum was assessed employing water-sensitive card imaging. Smaller drop sizes and relative amplitudes were produced by aerial applications. In turn, the largest droplet diameters and the lowest percentage of drops smaller than 100 μm were obtained when using air induction flat double-jet nozzles. The adjuvant did not interfere in the numerical and volumetric median diameters, the relative amplitude, or the volume rate of droplets smaller than 100 μm.

Keywords: spray quality, solution deposition, aerial, terrestrial, *Citrullus lanatus*

1. Introduction

The watermelon (*Citrullus lanatus*) retains the central region of Africa as its center of origin. It is a widely cultivated vegetable in Brazil, especially in semi-arid regions, where the climatic conditions are highly favorable for its cultivation, constituting an essential food for low-income populations (Landau & Silva, 2020).

The quality and quantity production of watermelon requires the effective control of pests, diseases, and weeds, which is directly related to spraying techniques. The most employed method for the protection of watermelon crops consists of terrestrial application using backpack sprayer or tractorized hydraulic sprayers (Emmanuel & Oludele, 2019). Nevertheless, the operational advantages described by aerial spraying have caused a considerable increase in this form of application, although further research is required (Zhang et al., 2020; Liu et al., 2020).

The method of application of phytosanitary products is essential, but, most of the time, emphasis is given mainly to the applied product and little attention to the application technique. Knowledge of the employed product is not enough. Comprehension of the technology of agricultural pesticide application is fundamental. Furthermore, it is necessary to ensure that the product reaches its target efficiently, minimizing losses (Butts et al., 2021; Penney et al., 2021).

Ensuring that spray droplets exhibit uniform distribution and homogeneous sizes is a major factor which can interfere with pesticide application quality. Therefore, during application, overall caution should be given in order to avoid the production of extremely large or small droplets (Zhang et al., 2020). Large drops generate low surface coverage and drainage; on the other hand, they are less prone to wind displacement. Small droplets, although they enable optimal target coverage, may undergo problems such as drift and evaporation, with consequent risks regarding environmental contamination (Wang et al., 2020; Carvalho et al., 2017; Huang et al., 2011).

Hollow cone spray nozzles, which are similar to rotating atomizers used in agricultural aircrafts and sprinklers, are traditionally employed in the application of fungicides and insecticides, and have as a common characteristic the production, in general, of fine droplets. This attribute provides excellent coverage of the target, being, however, highly susceptible to drift. One way to reduce this problem is by using drift-reducing nozzles, or ones that produce coarse drops but provide a good coverage of the target, such as air induction flat double-jet nozzles (Hunter et al., 2020; Tang et al., 2016; Bueno et al., 2013).

One of the problems described when using air induction nozzles is the fact that some commercial brands do not provide sufficient information regarding the population and the size of the produced droplets, the potential drift risk, and their volumetric distribution (Zhang et al., 2020; Rojo et al., 2019).

The addition of adjuvants to the spray mix can aid in drift reduction. Numerous types of adjuvants, which operate differently, can be found on the market, and their potential characteristics include improved wetting, spreading, adherence, and leaf penetration (Zhang et al., 2021; Vieira et al., 2018), as well as reduced surface tension of the droplets by enhancing leaf coverage (Song et al., 2020; Machado et al., 2019). However, Zhang et al. (2020) reported that the addition of adjuvants can alter application performance, and may lead to positive or negative effects regarding product deposition on the target.

The biological efficacy of a phytosanitary treatment can be better evaluated if an analysis of the droplet population is performed following application. One of the tools employed for this assessment is the use of artificial targets, such as water-sensitive cards (Alves et al., 2017). When properly handled, these cards are valuable tools for determining the quality of sprays, particularly in aerial rotating atomizer applications, which do not allow for easy laboratory assessments of the drop spectrum, employing laser droplet analysis equipment, for example.

Therefore, in order to ascertain the quality of a pesticide spray application, it is necessary to evaluate the droplet spectrum. The objective of the present study was to assess the spectrum of drops produced in the aerial and terrestrial spraying of a watermelon plantation, varying the spray nozzles and the composition of the application solution under different operating conditions, given there is little information available in literature regarding the use of phytosanitary products in this crop.

2. Method

The experiment was conducted at the experimental farm Aeroverde Group, located in the municipality of Aracruz (19°49′11″ S and 40°16′27″ W; at an altitude of 100 m) in the State of Espirito Santo, Brazil. The laboratory analyses were carried out at the Laboratory of Mechanization and Application of Agricultural Defensives of the Northern University Center of Espirito Santo, at the Federal University of Esprito Santo, in São Mateus-ES, Brazil

The assessments were carried out in two areas, irrigated by drip irrigation, corresponding to two applications: the first on July 1, 2020, in Area 1; and the second on August 6, 2020, in Area 2, both of approximately 8.0 ha. During the years prior to the survey, the areas underwent watermelon and bean cultivation. The purpose of evaluating two distinct areas was to verify if the results exhibited similar tendencies with respect to the studied characteristics (droplet size spectrum), under different field conditions (mainly environmental conditions).

The employed cultivation system consisted of conventional planting, cultivated with hybrid watermelons using a 100-day cycle. Planting was carried out on March 19, 2020, in Area 1, and on April 15, 2020, in Area 2, by mechanized sowing, with 2.0 m × 2.0 m spacing and 0.02 m planting depths. All of the recommended cultural practices were carried out.

The experimental design was completely randomized, in a 6 × 2 factorial scheme, with five repetitions, composed of six forms of application and two solution compositions. The means of application corresponded to the combination of the ‘type of spray’ (aerial and terrestrial) and the ‘application volume’, as described in Table 1.

Table 1. Description of the experimental treatments

Description	Abbreviation
Terrestrial application using double flat spray nozzles (AITTJ60-1102VP), 200 kPa of pressure, 150 L ha^{-1} of solution volume, with and without adjuvant	T 150 IA
Terrestrial application using double flat spray nozzles (AITTJ60-11025VP), 500 kPa of pressure, 300 L ha^{-1} of solution volume, with and without adjuvant	T 300 IA
Terrestrial application using hollow cone spray nozzles (TX-VK10), 300 kPa of pressure, 150 L ha^{-1} of solution volume, with and without adjuvant	T 150 V
Terrestrial application using hollow cone spray nozzles (TX-VK18), 400 kPa of pressure, 300 L ha^{-1} of solution volume, with and without adjuvant	T 300 V
Aerial application using a Micronair AU500 rotating atomizer, 200 kPa of pressure, 12 L ha^{-1} of solution volume, with and without adjuvant	A 12
Aerial application using a Micronair AU500 rotating atomizer, 200 kPa of pressure, 25 L ha^{-1} of solution volume, with and without adjuvant	A 25

In the aerial applications, rotating screen atomizers were employed as a drop-breaking system, varying the position of the variable restriction unit (VRU) of the atomizer in order to obtain the assessed volumes.

The application solution was composed of water and water plus the adjuvant (0.5% v/v Phosphatidylcholine and propionic acid Li700®). According to the manufacturer, the adjuvant is non-ionic, reduces surface tension, and is anti-drift.

In the terrestrial applications, a constant-pressure (CO_2) costal sprayer was employed, equipped with a bar containing six nozzles that were spaced apart by 0.50 m, and 0.50 m in relation to the culture, retaining an average application velocity of 1.2 m s^{-1}. The total area of the experimental units was 70.0 m² (7.0 m wide and 10 m long), which were separated by a longitudinal distance of 10.0 m. In order to avoid the border effect, two lines on each side of the plot and 1.0 m from each end were discarded.

During the aerial applications, an Ipanema 202-A agricultural aircraft, supplied with eight Micronair AU 5000 rotating screen atomizers, was utilized. The flight height was 3.0 m in relation to the culture, at an application speed of 180 km h^{-1}, and the atomizer blades were placed at an angle of 45°. The size of the plots was 20,000 m^2, corresponding to 250.0 m in length and 80.0 m in width, which is equivalent to five 16-meter strides of the aircraft. Following application, a lateral distance of 50.0 m between each plot was established. The worked area corresponded to 2,000 m^2, of which 15.0 m of each side and 100.0 m of each end were discarded.

The sprayings were carried out perpendicularly to the wind direction, and the environmental conditions of the two assays were distinct. The experiment took place in July and august of 2020, the climatic conditions monitored and recorded by means of a meteorological station (Sigma Sensors®, model EMI-RX-500). In addition to being monitored at the time of the applications, the climatic conditions were monitored in the days and hours preceding the applications in order to standardize them, considering as appropriate ranges the temperatures not exceeding 30 °C, relative humidity between 55 and 80% and speed 0.5 and 2.5 m s^{-1}.

The droplet size spectrum were evaluated by the analysis of the water-sensitive cards, which retained dimensions of 76 × 26 mm. Before spraying, four cards were randomly placed within the worked area of each plot, all suspended by a wooden rod above the plant canopy, positioned horizontally and directed upwards, without leaf interference.

The quantification and characterization of the impacts on each water-sensitive paper label were performed immediately after the application of each treatment and drying of the labels using a wireless DropScope system, composed of application programs and a digital wireless microscope with digital image sensor with more than 2500 dpi. This allows him to estimate partially overlapping drops from approximately 35 µm. The following parameters were evaluated: mean volume diameter ($Dv_{0.5}$, µm), numerical median diameter (NMD, µm), relative amplitude (RA) and percentage of the applied volume of wich the droplets have less than 100 µm in diameter (Dv < 100).

Initially, the droplet size spectrum data were subjected to the Kolmogorov-smirnov normality and Levene variance homogeneity tests. Afterward, variance analysis (ANOVA) was performed, and, when a significant difference was verified, the means of the studied characteristics were compared using the Tukey test. The analyses were carried out with the aid of the R software (R Code, 2020).

3. Results

When analyzing the $Dv_{0.5}$ in the first application performed in Area 01, the interaction between the 'forms and volumes of application' and 'adjuvant' factors was not significant, indicating independence of the factors. Regarding the NMD variable, a significant interaction between the factors was observed, inferring dependence between them (Table 2).

Table 2. Volumetric median diameter ($Dv_{0.5}$) and numerical median diameter (NMD) of the sprayed droplets after the first aerial and terrestrial application onto the watermelon culture, with and without adjuvant addition to the spray solution

Forms and volumes of application (L ha^{-1})	$Dv_{0.5}$ (μm)			NMD (μm)		
	Adjuvant		Mean	Adjuvant		Mean
	Without	With		Without	With	
A 12	105	103	104 A	80 Aa	78 Aa	79
A 25	136	109	123 A	74 Aba	74 Aa	74
T 150 H	156	150	153 AB	100 ABCa	96 Aba	98
T 300 H	181	179	180 B	94 ABCa	90 Aba	92
T 150 AI	444	440	442 C	109 Ca	143 Cb	126
T 300 AI	470	473	472 C	106 BCa	109 Ba	108
Mean	249	242		94	98	
	VC = 16.14%			VC = 13.21%		
	$F_F = 140.07^{**}$; $F_A = 0.13^{ns}$; $F_{FxA} = 0.21^{ns}$			$F_F = 26.09^{**}$; $F_A = 2.14^{ns}$; $F_{FxA} = 3.88^{ns}$		

Note. H: hollow cone spray nozzle; AI: double air induction spray nozzle; VC: variation coefficient; F_F: calculated F value regarding the 'form of application' factor; F_A: calculated F value regarding the 'adjuvant' factor; F_{FxA}: calculated F factor regarding the interaction between the 'form of application' and the 'adjuvant' factors. Means followed by the same uppercased letter in a column, and lowercased letters in a row, do not differ between each other at a 5% level of significance by the Tukey test. ** significant at 0.01; ^{ns} not significant.

Regarding the RA and '< 100' variables, no significant interaction between the assessed factors was observed, indicating independence between them (Table 3).

Table 3. Relative amplitude (RA) and percentage of the sprayed volume composed of droplets with diameters inferior to 100 μm (< 100) after the first aerial and terrestrial application onto the watermelon culture, with and without adjuvant addition to the spray solution

Forms and volumes of application (L ha^{-1})	RA			< 100		
	Adjuvant		Mean	Adjuvant		Mean
	Without	With		With	Without	
A 12	0.843	0.803	0.823 A	48.37	47.95	48.16 D
A 25	1.090	1.070	1.080 B	24.79	35.73	30.26 C
T 150 H	0.930	1.003	0.967 AB	11.30	12.22	11.76 B
T 300 H	1.200	1.161	1.181 B	12.90	12.07	12.49 B
T 150 AI	1.231	2.022	1.627B	1.57	0.73	1.15 A
T 300 AI	1.221	1.082	1.152B	1.70	1.56	1.63 A
Mean	1.086	1.190		16.77	18.38	
	VC = 17.77%			VC = 28.40%		
	$F_F = 5.05^{**}$; $F_A = 2.12^{ns}$; $F_{FxA} = 0.93^{ns}$			$F_F = 90.32^{**}$; $F_A = 1.09^{ns}$; $F_{FxA} = 1.80^{ns}$		

Note. H: hollow cone spray nozzle; AI: double air induction spray nozzle; VC: variation coefficient; F_F: calculated F value regarding the 'form of application' factor; F_A: calculated F value regarding the 'adjuvant' factor; F_{FxA}: calculated F factor regarding the interaction between the 'form of application' and the 'adjuvant' factors. Means followed by the same uppercased letter in a column, and lowercased letters in a row, do not differ between each other at a 5% level of significance by the Tukey test. ** significant at 0.01; ^{ns} not significant.

In the second application (Area 2), the interaction between the 'forms and volumes of application' and 'adjuvant' factors was not significant, regarding both the $Dv_{0.5}$ and the NMD parameters. With respect to the two variables, smaller droplet sizes were obtained when using the rotating atomizers with volumes of 12 and 25 L ha^{-1} of solution. In contrast, the highest droplet size values were produced when using the double flat air induction nozzles, with volumes of 150 and 300 L ha^{-1} of solution (Table 4).

Table 4. Volumetric median diameter ($Dv_{0.5}$) and numeric median diameter (NMD) of the sprayed droplets after the second aerial and terrestrial application onto the watermelon culture, with and without adjuvant addition to the spray solution

Forms and volumes of application (L ha^{-1})	$Dv_{0.5}$ (µm)			NMD (µm)		
	Adjuvant		Mean	Adjuvant		Mean
	Without	With		With	Without	
A 12	108	96	102 A	70	60	65 A
A 25	120	121	121 AB	85	74	80 A
T 150 H	165	174	170 BC	106	100	103 B
T 300 H	171	200	186 C	100	103	102 B
T 150 AI	440	433	437 D	121	125	123 C
T 300 AI	418	421	420 D	106	96	101 B
Mean	237	241		98	93	
	VC = 12.40%			VC = 13.23%		
	$F_F = 121.21^{**}$; $F_A = 0.09^{ns}$; $F_{FxA} = 0.91^{ns}$			$F_F = 31.14^{**}$; $F_A = 1.20^{ns}$; $F_{FxA} = 1.01^{ns}$		

Note. H: hollow cone spray nozzle; AI: double air induction spray nozzle; VC: variation coefficient; F_F: calculated F value regarding the 'form of application' factor; F_A: calculated F value regarding the 'adjuvant' factor; F_{FxA}: calculated F factor regarding the interaction between the 'form of application' and the 'adjuvant' factors. Means followed by the same uppercased letter in a column, and lowercased letters in a row, do not differ between each other at a 5% level of significance by the Tukey test. ** significant at 0.01; ^{ns} not significant.

Regarding the RA and the '< 100' variables, no significant interaction between the assessed factors was observed, suggesting independence between them. The lowest RA (0.689) was described in the aerial application with 12 L ha^{-1}, indicating optimal droplet production uniformity, differing from all other treatments (Table 5).

Table 5. Relative amplitude (RA) and percentage of the sprayed volume composed of droplets with diameters inferior to 100 µm (< 100) after the second aerial and terrestrial application onto the watermelon culture, with and without adjuvant addition to the spray solution

Forms and volumes of application (L ha^{-1})	RA			< 100		
	Adjuvant		Mean	Adjuvant		Mean
	Without	With		With	Without	
A 12	0.777	0.601	0.689 A	43.70	62.40	53.05 C
A 25	1.045	1.088	1.067 B	28.60	36.61	32.61 B
T 150 H	1.098	1.044	1.071 B	12.21	11.80	12.01 A
T 300 H	1.222	1.111	1.167 B	10.66	7.78	9.22 A
T 150 AI	1.256	1.321	1.289 B	1.61	1.70	1.66 A
T 300 AI	1.138	1.173	1.156 B	2.25	3.23	2.74 A
Mean	1.089	1.056		16.51	20.59	
	VC = 17.00%			VC = 34.43%		
	$F_F = 9.01^{**}$; $F_A = 0.07^{ns}$; $F_{FxA} = 0.30^{ns}$			$F_F = 66.70^{**}$; $F_A = 3.81^{ns}$; $F_{FxA} = 1.90^{ns}$		

Note. H: hollow cone spray nozzle; AI: double air induction spray nozzle; VC: variation coefficient; F_F: calculated F value regarding the 'form of application' factor; F_A: calculated F value regarding the 'adjuvant' factor; F_{FxA}: calculated F factor regarding the interaction between the 'form of application' and the 'adjuvant' factors. Means followed by the same uppercased letter in a column, and lowercased letters in a row, do not differ between each other at a 5% level of significance by the Tukey test. ** significant at 0.01; ^{ns} not significant.

4. Discussion

The aerial application treatments (12 and 25 L ha^{-1}) produced the lowest droplet sizes ($Dv_{0.5}$): 104 and 123 µm, respectively; as well as the lowest NMD, which ranged from 74 to 79 µm. The highest values of $Dv_{0.5}$ (442 and 472 µm) and NMD (126 and 108 µm) were produced by 150 and 300 L ha^{-1} terrestrial applications, using double air induction spray nozzles, as shown in Table 2.

The volumetric diameter of the droplets was not altered by the addition of the adjuvant. Also, it did not interfere with the NMD values, except the 150 L ha^{-1} terrestrial application treatment with the double air induction spray nozzle, in which the use of the adjuvant increased the NMD value.

Zhang et al. (2021) reported that the addition of the phosphatidylcholine + propionic acid adjuvant to the spray solution did not alter the $Dv_{0.5}$ of the drops produced by the hollow cone spray nozzle. However, it caused a 30% reduction in the $Dv_{0.5}$ of the droplets emitted by the flat air induction nozzle.

In a study determining the effect of formulations on spray characteristics, it was established that air induction nozzles are more susceptible to changes in the physical properties of the solution, and their behavior does not always follow that of conventional hydraulic nozzles (Wei et al., 2020; Zhang et al., 2020; Vieira et al., 2018).

The fact that some manufacturers do not provide information regarding droplet size spectrum can be a problem when working with air induction nozzles. According to Vitória et al. (2019), such information is essential for nozzle selection, in order to obtain greater efficiency in target coverage and lower environmental risks.

The droplet set uniformity, or the droplet size variation spectrum, can be expressed by the RA, in which the higher the RA value, the larger the spray droplet size range. According to Vitória et al. (2019), the homogeneous droplet spectrum retains a relative amplitude value that tends to zero. The results of the present study indicate that the lowest RA was verified in the aerial treatment using a solution volume of 12 L ha^{-1} (0.823), and in the terrestrial treatment, with 150 L ha^{-1} of solution (0.967), using hollow cone spray nozzles, inferring greater homogeneity in droplet formation when compared to the venturi system of hydraulic flat double air induction nozzles (Machado et al., 2019; Huang et al., 2011).

Hussain et al. (2019) and Fritz et al. (2011) evaluated the uniformity of the set of droplets produced by aerial systems (hydraulic nozzles, rotating disc atomizers, and electrostatic systems), and also verified the lowest relative amplitude values with the use of atomizers (15 L ha^{-1}) and the electrostatic system (5 L ha^{-1}) in the canopy of a rice culture. The use of high-speed rotating atomizers in agricultural aviation generates a more uniform droplet spectrum (Tang et al., 2016), corroborating with the results described in the present study.

According to Moraes et al. (2019), the estimation of the drift potential of a spray can be evaluated by the percentage of droplets with diameters smaller than 100 µm. There is no standard value indicative of drift risk or safe application. Nevertheless, according to the same authors, volume values below 15% of droplets with diameters smaller than 100 µm are generally better suited for environmentally safe applications.

Therefore, aerial applications with the described droplet spectrum should be carried out under environmental conditions that are favorable for phytosanitary applications in order to reduce drift losses to a minimum, such as air temperatures lower than 30 °C, relative humidity higher than 55%, and wind speeds less than 12 km h^{-1}.

The air induction nozzles can reduce potential drift risks. However, the formation of thick and very thick droplets is possible, resulting in increased drainage of the solution and, consequently, reduced spray efficiency (Alves et al., 2018). Furthermore, according to Madureira et al. (2015) and Chechetto et al. (2013), the use of air induction nozzles can provide a similar performance to that of conventional spraying, as long as the spray operator receives information regarding how to initially select the nozzle and how to improve its performance.

No significant difference between the presence and absence of the adjuvant in the spray solution was observed regarding relative amplitude values and the percentage of droplets smaller than 100 µm. A laboratory study carried out employing TT 11002 and TTI 11002 nozzles, with the addition of the phosphatidylcholine + propionic acid adjuvant to the spray liquid, also showed no alteration in relative amplitude values (Alves et al., 2018).

When evaluating droplet sizes using single, low-drift, and air induction hydraulic flat spray nozzles, with the same nominal flow rate, Hunter et al. (2020), Bueno et al. (2013) and et al. (2011) also reported that the air induction nozzles produced larger droplet sizes and retained lower propensity to drift, which corroborates with the results obtained in the present study.

Adjuvants with surfactant properties, such as phosphatidylcholine + propionic acid, have the ability to reduce the surface tension of aqueous solutions applied to a crop, improving leaf adherence (Alves et al., 2018)). This property can lead to a decrease in droplet size; however, the magnitude of this process is not large and varies according to the employed nozzle (Laio et al., 2015). This fact may explain the non-alteration of the volumetric and numerical median diameters with the addition of the adjuvant to the spray solution, observed in the present study.

Regarding the nozzles that operate with hydraulic pressure, the production of significantly uneven drops has been described, which hampers adequate target coverage. The development of technologies that produce more uniform drops is required in order to reduce the number of extremely small or large droplets (Vitória et al., 2019). The adoption of spray equipment that employs rotating atomizers as a drop-breaking system is an option.

The aerial application using 12 L ha^{-1} exhibited the largest percentage of spray droplets smaller than 100 µm, equivalent to 53.05%, differing from the other treatments. This type of droplet spectrum is highly susceptible to drift risk. It is noteworthy that, according to necessity, one can increase the size of the generated droplets by simply changing the angle of the rotating atomizer blades. There are also commercial rotating atomizers that contain specific devices to increase droplet size.

The use of the adjuvant did not significantly interfere with the relative amplitude values and the percentage of droplets smaller than 100 µm. Most of the adjuvants that retain spreader functions, found on the market, have surface tension-reducing properties in their composition, which alter the droplet size. However, the magnitude of this process is not very large and varies according to the employed spraying system.

According to Zhang et at. (2021), Machado et al. (2019) and Madureira et al. (2015), the addition of adjuvants can alter application performance. Therefore, the origin of these products and the implications of their use must be known before acquisition and use.

5. Conclusions

Rotating atomizers provide larger droplet sizes, while when using double air induction spray nozzles, the sizes are smaller. The diameter of the volumetric median, the relative amplitude, and the percentage of droplets smaller than 100 µm are not altered by adjuvant addition to the spray solution. The pressure regulation and the two solution volumes (12 and 25 L ha^{-1}), employed in the aerial application, produced the lowest relative amplitude of the droplet spectrum. However, both volumes resulted in a higher percentage of droplets that were susceptible to drift risk (smaller than 100 µm), when subjected to the adopted pressure.

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