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Spectrum of spray droplets with different nozzles and adjuvants

Luana de Lima Lopes[1], Elton Fialho dos Reis[1]

[1] Universidade Estadual de Goiás, Departamento de Engenharia Agrícola, Anápolis-GO, Brasil. E-mail: luanalopes100@yahoo.com.br; fialhoreis@ueg.br

ABSTRACT: Successful application of agrochemicals depends on factors such as the droplet size, nozzle type and solution composition. In this context, the objective of this study was to evaluate the spectrum of spray droplets with different spray nozzles by means of direct measurement. The experiment was conducted in a completely randomized design, with a factorial scheme 2 x 4 x 2 + 2 (nozzles x adjuvants x concentrations + controls), with four replicates. Used nozzles were the CVI 11002 and TVI 800075, the adjuvants were the Break-Thru®, Haiten®, Iharaguen-S® and Orix® additives added to the solution at the concentrations of 100 and 150%, and the control, without adjuvant. A particulate analyzer was used to obtain the droplet spectrum. The diameter of the volumetric median, diameter of the numerical median, relative amplitude and percentage of the volume of droplets smaller than 100 µm. The spray nozzle CVI 11002 presented the diameter of the favorable volumetric median for the solutions application and safety against drift and a more homogeneous droplet spectrum. The Break-Thru® adjuvant had lower risk of drift, and the increased concentration of Orix® adjuvant increased the homogeneity of the droplet spectrum.

Key words: application technology; image analysis; real droplet size

Espectro de gotas de caldas de pulverização com diferentes pontas e adjuvantes

RESUMO: O êxito na aplicação de produtos fitossanitários depende de fatores como tamanho de gota, tipo de ponta e composição da calda. Nesse contexto, objetivou-se avaliar a interferência de adjuvantes, adicionados a calda de pulverização, no desempenho das pontas quanto às características de espectro de gotas gerado por meio de medição direta. O experimento foi conduzido em delineamento inteiramente ao acaso, com esquema fatorial 2 x 4 x 2 + 2 (pontas x adjuvantes x concentrações dos adjuvantes + testemunhas), com quatro repetições. Foram utilizados as pontas CVI 11002 e TVI 800075, os adjuvantes Break-Thru®, Haiten®, Iharaguen-S® e Orix® adicionados à calda nas concentrações de 100 e 150%, e a testemunha, sem adjuvante. Para a obtenção do espectro de gotas foi utilizado um analisador de partículas por imagens. Foram avaliados o diâmetro da mediana volumétrica, diâmetro da mediana numérica, amplitude relativa e percentagem do volume de gotas menores de 100 µm. A ponta de pulverização CVI 11002 apresentou o diâmetro da mediana volumétrica favorável para a aplicação das caldas e segurança contra deriva e espectro de gotas mais homogêneo. O adjuvante Break-Thru® apresentou menor risco à deriva e o aumento da concentração do adjuvante Orix® elevou a homogeneidade do espectro das gotas.

Palavras-chave: tecnologia de aplicação; análise de imagens; tamanho real de gotas

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Introduction

In addition of knowing the applied product, it is also essential knowing its application form in order to ensure that the product reaches the target efficiently, minimizing the drift losses (Madureira et al., 2015).

Technical specifications with the droplet size ranges are found in the catalogs, but they can change according to the spray solutions physical characteristics, environmental conditions, machinery engineering, used methodology, among others (Yan et al., 2017; Carvalho et al., 2017; Parafiniuk et al., 2017; Carvalho et al., 2018). Choosing the droplet pattern is important, as it directly influences the coverage of the target and risks of drift losses (Mota & Antuniassi, 2013).

Flat spray nozzles work at a lower pressure, thus tending to produce thick or heavier droplets, which then reduces the drift and evaporation losses (Cunha & Peres, 2010). On the other hand, in conical jet nozzles with air induction, the air bubbles inside the droplets interfere with the transport and help to reduce the loss when droplets collide with the surface (Matthews, 2000).

When adding adjuvants to the spray solution, Yu et al. (2009), found the greater spread effect of the droplets when depositing on the target. Cunha et al. (2010), report that the droplets formation can be significantly changed, since these products alter the solutions physical properties.

Most devices that evaluate the droplet spectrum in real time employs the laser diffraction technique, however, it can present accuracy problems if used with liquids of different physical-chemical composition (Murphy et al., 2004). The limitations of these techniques and the recent improvements in digital image processing and cost reductions have increased interest in high-speed imaging techniques for agricultural applications (Hijazi et al., 2012).

Most imaging techniques use a background light for illuminating the droplets and acquiring their shadow graphics, from which their properties are then extracted. They allow photographs of the exposure times up to one microsecond to be taken, in one plane at a time (Ju et al., 2012).

The behavior of the solution with adjuvants sprayed with different spray nozzles can present different droplets spectra. However, there is little information available about this, mainly for the application of fungicide solution under these conditions. Therefore, the present study aimed to evaluate the interference of adjuvants, added to the spray, on the nozzles performance, regarding the spectrum characteristics of generated droplets.

Materials and Methods

The experiment was conducted at the Agricultural Engineering Laboratory, part of the Exact and Technological Sciences Campus from the State University of Goiás – UEG, in the municipality of Anápolis-GO (16°19' South and 48°57' West), under controlled temperature conditions (25 °C), in May 2017.

The used experimental design was the completely randomized, with a factorial scheme of treatments 2 x 4 x 2 + 2 (nozzles x adjuvants x concentrations + controls), with four replicates. Treatments consisted of two nozzles (CVI 11002 - standard flat jet, TVI 800075 - empty conical jet with air induction), four adjuvants (Break-Thru®, Haiten®, Iharaguen-S® and Orix®) added to the spray solution with the systemic fungicide Sumilex 500 WP (description in Table 1), two concentrations of the adjuvant dose (100 and 150%, described in Table 2), and the control groups that contained only water with fungicide, without adjuvant addition, with four replicates. The 100% dose represents the one indicated by the adjuvant manufacturer.

Choosing the CVI 11002 (standard flat jet) and TVI 800075 (empty conical jet with air induction) nozzles, both from the JACTO brand, was due to their use for spraying solution with systemic fungicides, according to the manufacturers description.

Pressure used for the CVI 11002 and TVI 800075 nozzles was of 137.9 and 517.1 kPa, respectively, which are found in the working range of these said nozzles.

For obtaining the droplets spectrum, an image particle analyzer, the Shadow Sizer System (Dantec Dynamics Inc.)

Table 2. Concentration description of the used adjuvants.

Commercial name Adjuvants	100% dose	150% dose
	(%v v^{-1})	
Break-Thru®	0.10000	0.15000
Haiten®	0.01500	0.02250
Iharaguen-S®	0.01000	0.01500
Orix®	1.50000	2.25000

Table 1. Description of adjuvants and fungicide used in the experiment, according to the product instructions.

Commercial name	Composition	Formulation	Concentration of a.i.*
Break-Thru®	Polyether-polymethyl siloxane copolymer	Soluble Concentrated	1000 g L^{-1}
Haiten®	Polyoxyethylene alkyl phenol ether + inert ingredients	Concentrated Aqueous Solution	200 g L^{-1}
Iharaguen-S®	Polyoxyethylene alkyl phenol ether + inert ingredients	Liquid	200 g L^{-1}
Orix®	Mineral oil + inert ingredients	Emulsifiable Concentrated	800 g L^{-1}
Sumilex 500 WP**	Procimidone + inert ingredients	Wettable powder	1000 g ha^{-1}

*Active ingredient; ** Fungicide.

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was employed. Characterization was performed in real time by the Software Dynamic Studio, version 2016ª. The system analyzed the droplets spectrum from the shadow projected by the particles captured by the camera, which was positioned opposite to the illumination source (LED). From processing the images captured by the camera, the diameter and volume of the droplets were then identified.

The used digital camera is a FlowSense EO 4 Mpx with resolution of 2352 x 1768 pixels and frequency of 41 frames per second, with Zeiss Rokinon 100 mm f/2.8 Macro Lens.

Droplets were evaluated at a height of 0.5 m in relation to the spraying nozzle and the reading point in a way that the measurement accounted for the droplets transversely to the produced jet (Guler et al., 2007).

The spray solution was placed in a 5 L capacity cylindrical reservoir, and the liquid pressurization was through compressed CO_2, stored in another canister, in order to maintain constant pressure. Environmental conditions were monitored during the experiment with an air temperature of 25 ± 3 ºC and a relative humidity of 55 ± 5%, with no wind and external luminosity, as the analyzes were performed with the lights off and in a closed environment. 2 L of spray solution were formulated for each replicate, prepared in 2 L beakers at a temperature of 25 ºC and then placed in 2 L plastic containers, always prepared on the same day of use.

For characterizing the droplet spectrum, DVM (Diameter of the volumetric median), in µm, DNM (Diameter of the numerical median), in µm, RA (Relative amplitude) and of the volume of droplets smaller than 100 µm (% droplets < 100 µm) were all evaluated.

Data were submitted to the Hartley test to verify the homoscedasticity condition and afterwards, the analysis of variance was held by applying the F test, at 5% probability. When significant, their means were compared with the Tukey test, at 5% probability. For all statistical analyzes, the Software SISVAR 5.6 (Ferreira, 2014) was employed.

Results and Discussion

Values of the mean squares and the respective statistical significance related to the variables analyzed are displayed in Table 3, showing that the variables DVM, DNM, RA and % volume of droplets < 100 µm were all influenced by the used treatments.

Table 4 shows a difference found for the diameter of the volumetric median (DVM) and diameter of the numerical median (DNM) regarding the different nozzles. The DVM and DNM values were higher for the CVI 11002 nozzle (standard flat jet), with 264.66 and 142.41 µm, respectively. However, for the TVI 800075 nozzle (empty conical jet with air induction) the diameters were 157.72 µm for DVM and 112.78 µm for DNM. Regarding the control (water + fungicide), the nozzles had the same DVM and DNM performance, which was the same for the CVI 11002 nozzle. Madureira et al. (2015), when analyzing the droplet spectrum of an inclined flat jet nozzle, found DVM values ranging from 226.31 to 301.55 µm, corroborating with those found in this study.

Cunha et al. (2004) found DVM values that ranged from 83 to 129 µm, when using empty conical jet nozzles, with these being lower than those found in this study. However, since the nozzle used in this experiment was an empty conical nozzle

Table 4. Means from the diameter of the volumetric median (DVM) and Means from the diameter of the numerical median (DNM) of the spray solution droplets.

Nozzle	DVM (µm)		DNM (µm)	
	Mean			
TVI 800075	157.72	B	112.78	B
CVI 11002	264.66	A	142.41	A
	Water + Fungicide			
TVI 800075	169.81	B	118.31	B
CVI 11002	296.63	A	166.81	A

*Means followed by the same letter, in the column, do not statistically differ by the F test t 5% of probability.

Table 3. Synthesis of the analysis of variance for the diameter of the volumetric median (DVM), diameter of the numerical median (DNM); relative amplitude (RA) and % volume of droplets < 100 µm for the different nozzles, adjuvants and adjuvant dose concentrations.

Variation source	DoF	Mean Square of Evaluated Variables							
		DVM		DNM		RA		% volume of droplets <100µm	
T	1	182970.06	**	14042.25	**	5.65	**	1828.85	**
A	3	1812.54	NS	851.35	NS	0.41	*	181.53	**
C	1	1024.00	NS	1296.00	NS	0.01	NS	138.25	NS
T x A	3	3864.27	NS	614.46	NS	1.01	**	81.20	NS
T x C	1	1387.56	NS	370.56	NS	0.63	*	32.38	NS
A x C	3	6709.88	NS	451.13	NS	0.38	*	78.70	NS
T x A x C	3	4218.19	NS	692.94	NS	0.02	NS	84.42	NS
Cont	1	32162.82	**	4704.50	**	2.22	**	105.15	NS
Fac x Cont	1	3451.56	NS	1593.34	NS	0.09	NS	83.71	NS
Residual	54	1693.65		601.31		0.14		38.59	
Total	71	5102.36		877.56		0.30		78.17	
Mean		218.53		132.58		2.51		15.86	
CV (%)		23.01		27.23		15.53		39.89	

*Significant at 5% of probability by F test; ** Significant at 1% of probability by F test; NS not significant at 5% of probability by F test; Nozzle (T), Adjuvant (A), Adjuvant concentration (C), Control (Cont), Factorial (Fac).

with air induction, the droplets spectrum tends to be larger than the same nozzle without induction. The Venturi system present in these nozzles, combined with the pre-orifice, allows the formation of larger droplets with small air bubbles inside them (Nuyttens et al., 2007).

According to the ASABE standards (2009) and the values found in the study, the droplets spectrum produced by the CVI 11002 and TVI 800075 nozzles is classified as medium (236-340 µm) and fine (106-235 µm), respectively.

Lasmar (2014), when verifying different adjuvant concentrations (mineral oil) in water, observed that in the different concentrations, from 5 to 20%, (of the total solution volume), the mean values of DVM did not change, for flat and conical jets, at an air pressure of 39.23 kPa. Therefore, DVM values were not dependent on the adjuvant concentration, as in this study, in which there was no difference between the concentrations.

There was no difference for DVM and DNM, for solutions with and without adjuvants. Iost (2008), evaluating the effect of adjuvants with anti-oxidative potential (nonylphenolethoxylated + ethylene oxide, phosphatidylcholine + propionic acid, nonyl phenol ethoxylated, lecithin and glycolsilane polymer) on the droplets size, found little effect on the diameter of the volumetric median, in the recommended dose by the manufacturers.

Most adjuvants with a spreading function have surface tension reducing properties in their composition. This, in turn, can also lead to a decrease in the droplets size; however, the magnitude of this process is not very large and varies according to the used nozzle (Butler Ellis et al., 2001).

The interaction between nozzles and adjuvants, nozzles and concentrations and concentrations and adjuvants, were significant for RA (Table 5), demonstrating that the droplet spectrum varied between treatments, interfering in the uniformity of the droplet size.

Regardless of the used adjuvant, the solutions sprayed with the CVI 11002 nozzle showed a lower or equal RA value when compared to the TVI 800075 nozzle (Table 5). Among

adjuvants, Haiten®, when added to the solution, is the one that decreases the droplets homogeneity in a more compelling way, when applied with the TVI 800075 nozzle.

Increasing the adjuvant concentration influenced the RA only for the Orix® adjuvant. When the concentration increased, the mean RA decreased, or, in other words, with the increase in concentration, the droplet spectrum showed greater homogeneity for this adjuvant.

According to Baio et al. (2015), the variation shows that the interaction between adjuvants and used nozzles in agricultural applications are complex, and yet the authors verified the need for a more accurate classification of these inputs together with the Ministry of Agriculture, in which each use condition may have different performance in the field.

In order to verify the increase in spray solution quality, it is necessary improving the applied droplet patterns, mainly the homogeneity of the droplet spectrum. The higher the value of the relative amplitude is, the larger the droplet size range will be, which will possibly affect the treatment effectiveness (Reis et al., 2010).

The closer to zero the RA parameter is, more homogeneous the spectrum will be, increasing the chances of the target being reached and decreasing losses to the environment (Sasaki et al., 2015). However, this value is not found in commercial nozzles because they produce droplets of varying sizes (Sasaki et al., 2016).

Figueiredo et al. (2007), when evaluating the spectrum uniformity of the droplets produced by different flat jet nozzles, found values of RA ranging from 2.00 to 4.60, corroborating with those found in this study, which ranged from 2.01 to 3.34.

According to Christofoletti (1999), the higher the value of the relative amplitude, the larger the size range of the sprayed droplets will also be.

The percentage of droplet volume with diameters smaller than 100 µm (% volume of droplets < 100 µm) showed a difference between the nozzles and adjuvants, shown in Table 6.

The TVI 800075 nozzle had % volume of droplets < 100 µm greater than the values presented by the CVI 11002 nozzle. The Break-Thru® adjuvant had a lower % volume of droplets < 100 µm in relation to the Orix® adjuvant. Hence, with the use of the CVI 11002 nozzle, the application is less subject to drift.

Table 5. Means of the relative amplitude (RA) of the droplets spectrum from the spraying solutions.

	TVI 800075		CVI 11002	
Break-Thru®	2.64	Ba*	2.21	Ab
Haiten®	3.34	Aa	2.01	Ab
Iharaguen-S®	2.61	Ba	2.39	Aa
Orix®	2.50	Ba	2.09	Ab
	TVI 800075		**CVI 11002**	
100%	2.66	Aa**	2.26	Ab
150%	2.88	Aa	2.24	Ab
	100%		**150%**	
Break-Thru®	2.26	Aa*	2.58	ABa
Haiten®	2.54	Aa	2.81	Aa
Iharaguen-S®	2.63	Aa	2.37	ABa
Orix®	2.72	Aa	2.18	Bb

*Means followed by the same uppercase letter, in the column, and lowercase letter, in the row, do not differ statistically by the Tukey test t 5% of probability; **Means followed by the same uppercase letter, in the column, and lowercase letter, in the row, do not differ statistically by the F test at 5% of probability.

Table 6. Mean percentage of droplet volume smaller than 100 µm, from the spray solutions.

Nozzle	Mean (%)	
TVI 800075	22.35	A*
CVI 11002	11.66	B
Adjuvant		
Break-Thru®	13.41	B**
Haiten®	15.46	AB
Iharaguen-S®	17.91	AB
Orix®	21.23	A

*Means followed by the same letter, in the column, do not differ statistically by the F test t 5% of probability. **Means followed by the same letter, in the column, do not differ statistically by the Tukey test t 5% of probability.

And using the Break-Thru® adjuvant corresponded to a lower % volume of droplets < 100 µm, when compared to the Orix® adjuvant (Table 6).

Interpretation of the percentage data of the droplets volume with a diameter smaller than 100 µm, allows estimating the drift potential of the application, and according to Arvidsson et al. (2011), serves as a better indicator of drift danger than DVM, and thus, the higher this percentage, the greater the occurrence of drift will also be.

For the analyzed nozzles (Table 6), TVI 800075 has a high potential for drift risk, with mean of 22.35% volume of droplets < 100 µm. In general, values below 15% of the sprayed volume composed of droplets with a diameter smaller than 100 µm seem to be more suitable for a safe application (Cunha et al., 2003).

The CVI 11002 nozzle indicated a higher DVM (Table 4) and had a lower % volume of droplets < 100 µm (Table 6). The same occurs in the research by França et al. (2017), noting that where DVM values smaller than 150 µm happened, the highest drift rates occurred and there was a greater possibility of contaminating neighboring areas, for an experiment in wind tunnel and spraying with different nozzles and solutions with and without adjuvant. Showing that these values change in an inverse way.

According to Villalba & Hetz (2010), the combination of air temperature above 30 °C and relative humidity below 40% directly influence the evaporation of the spray droplets, especially fine droplets, with the factors what most affect these types of losses being the droplets size, the time it takes to reach the target and the distance from the target. For this research, the risk of these losses can occur with a greater proportion when using the TVI 800075 nozzle, as it had a higher percentage of droplets smaller than 100 µm.

Droplet size reduction is mainly desired when the application purpose is to provide good coverage to the target, since smaller droplets provide greater coverage (Bueno et al., 2013). Therefore, spraying with the TVI 800075 nozzle can provide a greater coverage of the target.

Conclusions

CVI 11002 spray nozzle, in laboratory conditions, presented a favorable DVM for the application of spray solutions and safety against drift, with medium sized droplets as well as a more homogeneous spectrum of droplets.

Addition of adjuvants to the solution did not change the DVM and DNM of droplets. The Break-Thru® adjuvant had less risk of drift and the increased concentration of the Orix® adjuvant increased the homogeneity of the droplets spectrum.

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