

2015

Physical and Biological Effects of Modified Polysorbate 20

Kevin Penfield
Croda Inc.

Bryan Young
Southern Illinois University


Julie K. Young
Southern Illinois University, julie.k.young@aphis.usda.gov

Greg R. Kruger
University of Nebraska - Lincoln, greg.kruger@unl.edu

Ryan Henry
University of Nebraska - Lincoln

See next page for additional authors

Follow this and additional works at: <https://digitalcommons.unl.edu/westcentresext>

 Part of the [Agriculture Commons](#), [Ecology and Evolutionary Biology Commons](#), and the [Plant Sciences Commons](#)

Penfield, Kevin; Young, Bryan; Young, Julie K.; Kruger, Greg R.; Henry, Ryan; and Lindner, Greg, "Physical and Biological Effects of Modified Polysorbate 20" (2015). *West Central Research and Extension Center, North Platte*. 96.
<https://digitalcommons.unl.edu/westcentresext/96>

This Article is brought to you for free and open access by the Agricultural Research Division of IANR at DigitalCommons@University of Nebraska - Lincoln. It has been accepted for inclusion in West Central Research and Extension Center, North Platte by an authorized administrator of DigitalCommons@University of Nebraska - Lincoln.

Authors

Kevin Penfield, Bryan Young, Julie K. Young, Greg R. Kruger, Ryan Henry, and Greg Lindner

STP 1579, 2015 / available online at www.astm.org / doi: 10.1520/STP157920130188

Kevin Penfield,¹ Bryan Young,² Julie Young,²
Greg Kruger,³ Ryan Henry,³ and Greg Lindner¹

Physical and Biological Effects of Modified Polysorbate 20

Reference

Penfield, Kevin, Young, Bryan, Young, Julie, Kruger, Greg, Henry, Ryan, and Lindner, Greg, "Physical and Biological Effects of Modified Polysorbate 20," *Pesticide Formulation and Delivery Systems: 34th Volume, Translating Basic Science into Products*, STP 1579, Yasmith Bernal, Ed., pp. 76–93, doi:10.1520/STP157920130188, ASTM International, West Conshohocken, PA 2015.⁴

ABSTRACT

Three experimental polyoxyethylene sorbitan monolaurate derivatives were synthesized with molecular fingerprinting techniques applied to experimental materials, confirming the target compounds had been produced. Chemical property measurements were compiled that aligned with theoretical predictions and physical property measurements confirmed their intentional differences yielded the anticipated changes in surfactant behavior. Imidacloprid uptake data confirmed penetration of leaf cuticles was enhanced in the presence of polyoxyethylene sorbitan monolaurates with several experimental materials providing uptake equivalent to reference material. Select materials were included in field and greenhouse trials where observations included good biological response with a range of individual herbicides as well as improved control of volunteer glyphosate tolerant corn with mixtures of glyphosate and clethodim over the control nonionic surfactant adjuvant when applied as a tank-added adjuvant. Antagonism of annual grass control was not observed.

Manuscript received December 15, 2013; accepted for publication December 16, 2014; published online February 24, 2015.

¹Croda Inc., New Castle, DE 19720.

²Southern Illinois Univ., Carbondale, IL 62901.

³Univ. of Nebraska at Lincoln, North Platte, NE 68588.

⁴ASTM 34th Symposium on *Pesticide Formulation and Delivery Systems: Translating Basic Science into Products* on Oct. 22–24, 2013 in Jacksonville, FL.

Copyright © 2015 by ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959.

Used by permission.

Keywords

tween 20, tween 21, tween 22, tween 23, tween 24, tween 28, polysorbate 20, polysorbate 21, polysorbate 22, polysorbate 23, polysorbate 24, polysorbate 28, polyoxyethylene sorbitan monolaurate, physical properties, characterization, adjuvant

Introduction

The specific physical characteristics of active ingredients used in pesticides can impose technically challenging formulation design requirements if the molecule is to achieve its full potential. One adjuvant of the nonionic surfactant class that has found suitable utility across wide ranges of these highly variable active ingredients is polysorbate 20, very often identified in agricultural uses by its original trademarked name of TweenTM 20. TweenTM is a trademark of the Croda group of companies. It has been used widely in agrochemical formulations and commonly included as a candidate in adjuvant studies [1,2]. The range of physical and biological effects for polysorbate 20 has been thoroughly catalogued and can be categorized as: (1) emulsification, (2) solubilization, (3) spray retention, (4) wetting and spreading, (5) deposit formation and humectancy, (6) penetration and uptake, (7) transport or translocation, and (8) phytotoxicity [2]. In spite of its documented broadly successful use, the identification of one specific biochemical rationale explaining widespread use of this material as an adjuvant remains elusive.

While other polysorbates are also well investigated in the literature, polysorbate 20 was selected as the starting point for this experimental work based on (1) its widespread appearance in a broad cross section patent and research literature as a control or reference standard, (2) its fluid properties in bulk and non-gelling behavior upon dilution, and (3) its extensive dataset of ecological and toxicological properties which demonstrate desirable attributes [3–8].

Materials and Methods

MATERIALS

Polysorbate 20 is one member of the chemical family described as sorbitan ester ethoxylates [5]. It is the result of a series of chemical reactions leading to the production of complex mixtures comprised essentially of ethoxylated sorbitol and its anhydrides esterified with coconut or palm kernel fatty acids, primarily lauric acid with its reaction sequence identified in Fig. 1.

Ethoxylation enables adjustment of water soluble (hydrophilic) to oil soluble (lipophilic) portions or Hydrophile–Lipophile balance (HLB) [9]. The relationship of this aspect to changes in physical and biological effect is described in this paper using a limited number of variants of polyoxyethylene sorbitan monolaurate (CAS 9005-64-5) as test substances. The substances used in the development of the data presented in this paper appear in Table 1. All test materials were supplied by Croda Inc., New Castle, DE, at a nominal “active” concentration of 100 %.

The variability in composition between ethoxylated sorbitan monolaurate manufactured using different process conditions, raw materials, or process vessels could yield different results under the same test conditions, thus it is important to consider that different outcomes may be possible using other sources of polysorbate 20 or its variants.

CHEMICAL CHARACTERIZATION METHODS

NMR Spectroscopy

Test materials were submitted for nuclear magnetic resonance (NMR) analysis to provide comparative characterization (Bruker Avance III 400 MHz NMR spectrometer). Standard ^1H and ^{13}C NMR experiments were completed on each sample to ascertain their “average” chemical structure. Preparation for these materials included dilution of 300 ml of each sample with 400 ml of CDCl_3 solvent. A total of 16 scans were used to collect ^1H and 2000 scans to collect ^{13}C spectra.

MALDI Mass Spectroscopy

Samples were prepared in chloroform (solvent), dithranol (matrix), and lithium bromide (cationization agent) with the mass spectrometer (Bruker Reflex III) operated in positive ion, reflector mode. Mass spectra were collected in the range of 0 to 5575 Da with scale calibrated using a low MW peptide standard.

Saponification (SAP) and Hydroxyl (OHV) Values

Samples were analyzed according to standard test methods applied to sorbitan esters and polysorbates conforming to National Formulary specifications [10].

FIG. 1 Main chemical reactions and general process flow (top to bottom) involved in the production of polysorbate 20 and its variants.

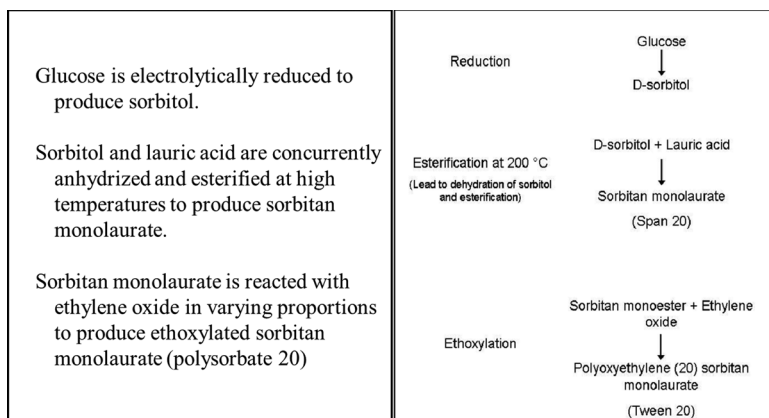


TABLE 1 Homologs of Tween 20 polysorbate 20 included in various assessments. Tween™ is a trademark of the Croda group of companies.

Product		HLB	M _n (Nominal)	Moles Ethylene Oxide					
				4–6	7–10	11–14	15–18	19–22	~80
Tween 21	Polysorbate 21	13.0	500	X					
Tween 22	Polysorbate 22	14.8	676		X				
Tween 23	Polysorbate 23	15.8	852			X			
Tween 24	Polysorbate 24	16.5	1028				X		
Tween 20	Polysorbate 20	17.0	1204					X	
Tween 28	Polysorbate 28	17.7	3844						X

PHYSICAL TEST METHODS

Measurement of Equilibrium Surface Tension (EST)

Aqueous solutions (0.1 and 0.2 wt.%) were equilibrated for 24 h prior to measurement by tensiometer (Kruss K10ST) using a Wilhelmy plate. Temperature was controlled at $25.0^{\circ}\text{C} \pm 0.1^{\circ}\text{C}$ with validation using HPLC grade water. Samples were monitored over 15 min with value recorded for at least two aliquots and average values reported.

Contact Angle Measurement

Aqueous solutions (0.2 wt.%) were equilibrated for 24 h prior to application on a microscope slide covered in parafilm. Then, 5 ml droplets were applied using a micropipette and contact angle measured by goniometer (Ramé-Hart) on each side of ten droplets with average contact angle reported.

Imidacloprid Uptake

Franz cells ($\text{Ø} = 9 \text{ mm}$; $V_{\text{Receptor}} = 5 \text{ ml}$; $V_{\text{Donor}} = \text{ml}$; PermeGear, Hellertown, PA) were used for diffusion experiments. Isolated cuticles from apple leaves (*Malus domestica* cv. “Golden Delicious”) were prepared according to the method previously described [11]. The donor compartment was removed to aid deposit formation. Experiments were performed at controlled temperature (20°C) and relative humidity (58 %). The donor medium was unformulated pesticide containing 0.5 g/l of imidacloprid and 2.5 g/l adjuvant in 5 mM lactic acid (prebuffered with KOH) preserved with 0.5 mM sodium azide. The receptor solution was 10 mM sodium phosphate buffer pH 6.0 containing 0.1 mM sodium azide. Experimental concentrations were chosen for initial evaluation in *in vitro* testing and for analysis. HPLC-UV was used to assay imidacloprid concentration using an Agilent 1260 Quaternary LC system.

Spray Quality

Analysis was conducted according to ASTM E2798-11 [12] by passing the width of the plume across the laser droplet size analyzer (Sympatec HELOS Vario KR w/R7 lens) by means of a linear actuator. Test solutions and controls were sprayed (≥ 3 replicates) through an extended range flat fan nozzle (TeeJet XR11004) operated at 40 psi with three or more replicates and mean driftable fine droplet fraction (vol. % $< 105 \mu\text{m}$) reported. Samples containing drift reduction technology (DRT) agent were formulated by mixing the agent (described as a fatty acid polyol ester and identified as Atplus DRT-100 as supplied by Croda Inc.) with polysorbate 20 variant at 50°C at 300 rpm in a laboratory mixer for 30 min to form a homogenous liquid. Atplus is a trademark of Croda.

BIOLOGICAL TEST METHODS

Adjuvant performance was assessed in field and greenhouse trials under the supervision of Dr. Bryan Young or Dr. Julie Young of Southern Illinois University (SIU).

TABLE 2 Tabulated data interpretation legend. Statistical groupings sharing at least one letter in common are not significantly different from one another.

Green = Significantly Greater		Yellow = Equivalent		Red = Significantly Lower	
71	ab	43	e-h	25	n
Mean Percent Control	Statistical Group	Mean Percent Control	Statistical Group	Mean Percent Control	Statistical Group

Studies were randomized complete block design (3 replicates) conducted at different location. Mean % weed control was calculated and reported for each treatment with statistical analyses by least significant difference (LSD) at the $P = 0.05$ level of significance. In tabulated data, treatment means including the same letter are not significant. The legend for interpreting tabulated data appears in [Table 2](#).

Sublethal active ingredient rates were used to highlight the adjuvant effect where the control adjuvant applied was a nonionic surfactant included at 0.25 vol. % spray mixture and formulated as specified in [Table 3](#).

Control of weeds with herbicides and experimental polysorbates was compared to weed control resulting from herbicides and either control N-Iodosuccinimide (NIS) adjuvant and/or polysorbate 20. Ammonium sulfate (AMS) was applied with experimental treatments and controls at 0.42 wt. % in spray solution.

Results and Discussion

CHEMICAL PROPERTIES

NMR Spectroscopy

Polysorbate 20 and its variants were submitted for NMR analysis and comparative characterization. Standard ^1H and ^{13}C NMR experiments were completed on each sample. All materials were confirmed to be ethoxylated sorbitan monolaurate type materials, varying in degrees of ethoxylation. The average degree of ethoxylation for each of the materials analyzed appears in [Table 4](#).

[Figures 2-5](#) contain comparative NMR spectra for polysorbate 24 and polysorbate 20. Since polysorbate 20 is comprised of a complex mixture of related components, each of varying molecular weight and construction, evaluation of similarities

TABLE 3 Control NIS adjuvant composition.

Component	Percent (wt.%)
Polyoxyethylene-9-nonylphenol	50
C ₁₆₋₁₈ and C ₁₈ unsaturated fatty acids	40
Propylene glycol	5
Water	5

TABLE 4 Average moles of ethylene oxide added to sorbitan monolaurate as determined by NMR based on non-TFA exchanged ¹H NMR data.

Product	Chemistry	Moles Ethylene Oxide
Polysorbate 21	Polyoxyethylene 4 sorbitan monolaurate	4.1
Polysorbate 22	Polyoxyethylene 8 sorbitan monolaurate	8.9
Polysorbate 23	Polyoxyethylene 12 sorbitan monolaurate	12.8
Polysorbate 24	Polyoxyethylene 16 sorbitan monolaurate	16.8
Polysorbate 20	Polyoxyethylene 20 sorbitan monolaurate	20.4

between polysorbate 20 and its variants by whole product analysis such as NMR is highly relevant. The ¹H NMR spectra appearing in [Figs. 2](#) and [3](#) share virtually identical peak chemical shifts and relative intensities. This confirms the materials being compared contain the same chemical constituents and are of virtually identical composition.

FIG. 2 ¹H NMR Spectrum for polysorbate 24.

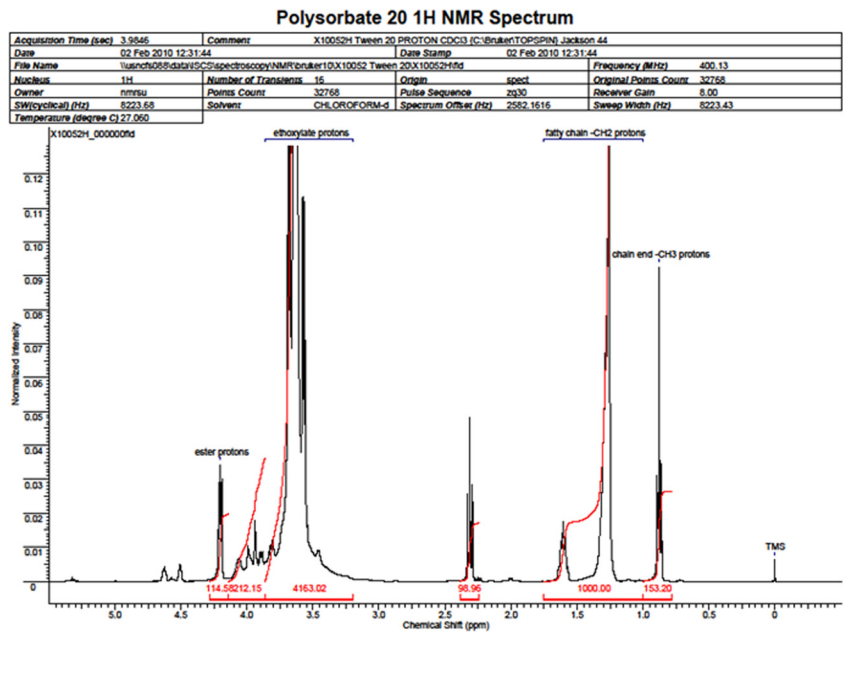
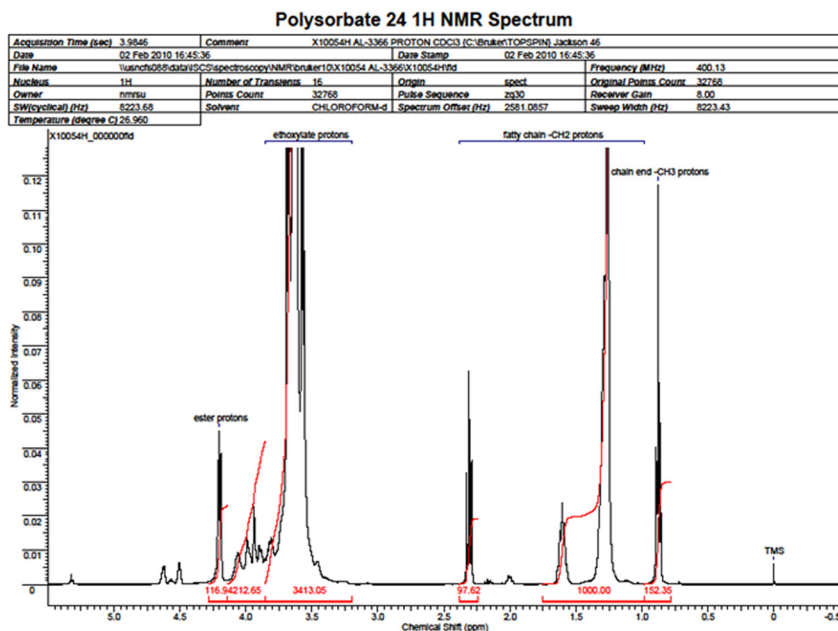


FIG. 3 ^1H NMR Spectrum for polysorbate 20.

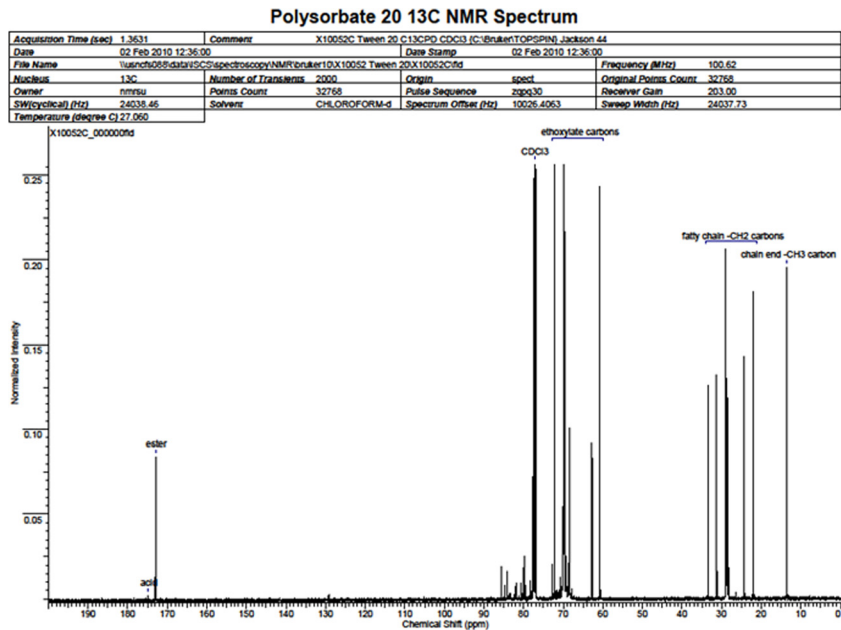
As with the preceding ^1H NMR spectra, the ^{13}C NMR spectra that appear in **Figs. 4** and **5** also share virtually identical peak chemical shifts and relative intensities. This confirms the materials being compared contain the same chemical constituents and are of virtually identical composition in terms of structural variations.

MALDI Mass Spectroscopy

MALDI spectra were collected fit to the following five species: (1) isosorbide ethoxylate, (2) isosorbide ethoxylate monolaurate, (3) sorbitan ethoxylate, (4) sorbitan ethoxylate monolaurate, and (5) sorbitan ethoxylate dilaurate. One sample was found to additionally contain sorbitan ethoxylate trilaurate. Fit of spectra did not indicate contributions from esters of other fatty acids, thus confirming their composition to be laurates. The predominant species confirmed present in each spectrum is sorbitan ethoxylate monolaurate. The only exception to this was for polysorbate 21, where the predominant species were the mono- and dilaurate esters of sorbitan ethoxylate.

Exemplifying the similarity between materials, homolog peak distributions detected for polysorbate 24 show slightly reduced means in comparison to the same set of homolog peaks for polysorbate 20 as can be seen in **Fig. 6**. Polysorbate 20 and polysorbate 24 peaks show similar molecular weight distributions varying in average in proportion to the targeted degree of ethoxylation on sorbitan monolaurate.

FIG. 4 ¹³C NMR Spectrum for polysorbate 24.



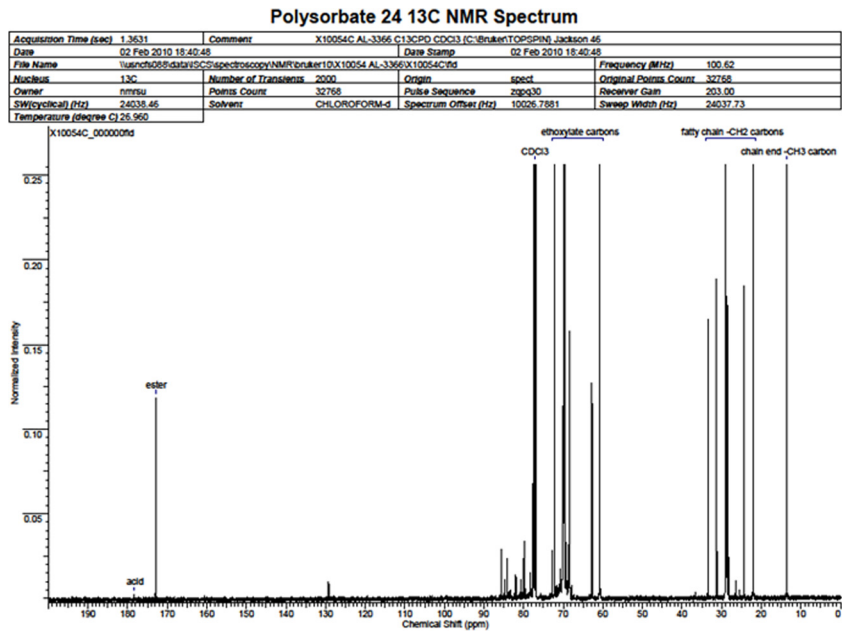
The same relationship between homolog peak distributions and the variation in their average molecular weights were observed in all polysorbate 20 variants analyzed (data not reported).

The same homolog series were confirmed to be present in both materials, establishing that the same mixture of ethoxylated substrates are present but are present in slightly varying molecular weight distributions as provided in [Table 5](#).

Taken together, the NMR and MALDI data on polysorbate 20 variants indicates the materials tested share the same chemical identity and vary in composition only by distribution of molecular weights. These differences relate to the amount of ethylene oxide incorporated into the ethoxylated sorbitan ester variant. The results of molecular characterization confirm the differences in composition targeted by synthesis.

The predicted values for each specification parameter (SAP and OHV) were calculated by interpolating the range of values between polysorbate 20 and polysorbate 21. The targeted variations in polysorbate 20 composition yielded actual values that were consistent with predicted values as appear in [Fig. 7](#). Lower actual versus predicted saponification and hydroxyl values suggest increased rates of ethylene oxide incorporation resulting in higher molecular weights. This appears consistent with the results of NMR and MALDI appearing in [Tables 4](#) and [5](#), respectively.

FIG. 5 13C NMR Spectrum for polysorbate 20.



PHYSICAL PROPERTIES

The targeted variations in polysorbate 20 composition yielded changes in surface active behavior consistent with theory [12]. Equilibrium surface tensions and contact angles increased in proportion with relative degree of ethoxylation with results for polysorbate 20 variants appearing in Table 6.

FIG. 6 Comparative MALDI Spectra of polysorbate 20 and polysorbate 24.

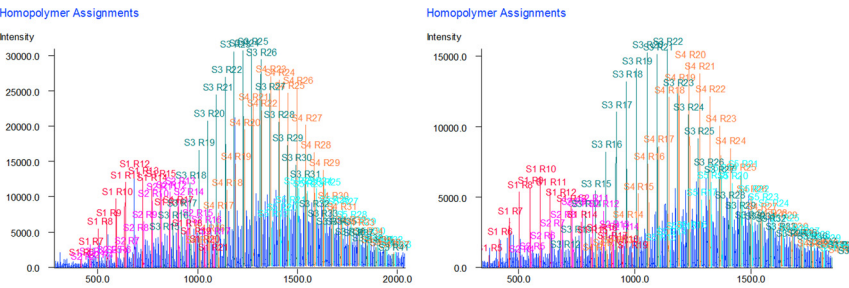


TABLE 5 Number average molecular weight (M_n) as determined by MALDI.

Product	Chemistry	M_n (MALDI)
Polysorbate 21	Polyoxyethylene 4 sorbitan monolaurate	642
Polysorbate 22	Polyoxyethylene 8 sorbitan monolaurate	809
Polysorbate 23	Polyoxyethylene 12 sorbitan monolaurate	1044
Polysorbate 24	Polyoxyethylene 16 sorbitan monolaurate	1180
Polysorbate 20	Polyoxyethylene 20 sorbitan monolaurate	1260

Changes in polysorbate 20 composition yielded differences in imidacloprid uptake, although these were not significantly different from one another. Imidacloprid uptake for treatments containing polysorbate 20 or its variants were significantly greater than treatments containing no adjuvant. Results appear in [Fig. 8](#).

Spray characterization results for polysorbate 20 and its variants with and without included drift reduction technology (DRT) appear in [Table 7](#). The values appearing in the columns labelled Dv10 and Dv50 are the mean droplet diameter for the lowest 10 % of droplets by volume and volume median diameter, respectively. Relative span is a calculated value derived by dividing the difference between Dv10 and Dv90 (the mean diameter for the lowest 90 % of droplets by volume) by volume median diameter and is representative of droplet size range correlating to the slope of cumulative droplet size distribution. Color and lettering associated with tabulated numeric values relate to statistical significance as explained in [Table 2](#).

FIG. 7 Variation in saponification value (SAP) and hydroxyl value (OHV) data for polysorbate 20 variants as a function of ethoxylation degree.

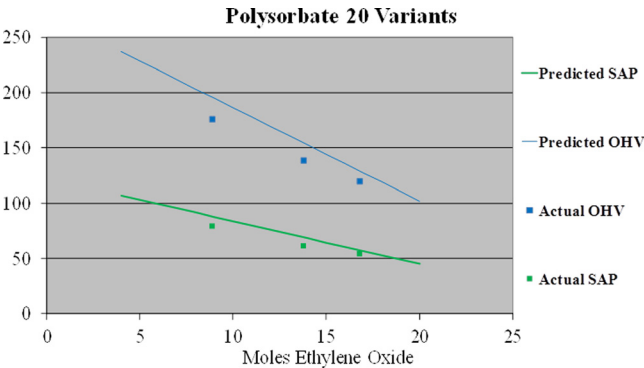


TABLE 6 Mean equilibrium surface tension and contact angles measured for polysorbate 20 variant solutions in deionized water.

Material	Concentration (wt. %)	Surface Tension (mN/m)	Contact Angle (°)
Polysorbate 21	0.2	28.1	58.1
Polysorbate 22	0.2	30.7	60.5
Polysorbate 23	0.2	32.4	62.8
Polysorbate 24	0.2	33.8	71.8
Polysorbate 20	0.2	35.7	74.3
Water (deionized)	N/A	72.2	105.3

Targeted variations in polysorbate 20 variant composition yielded differences in several key measures characterizing spray quality including statistically significant changes in Dv10, Dv50, relative span and vol. % of droplets with sizes below 105 μm relative to a control containing a mixture of glyphosate and water conditioner (glyphosate as RoundUp PowerMax and water conditioner as ammonium sulfate). In most cases, inclusion of polysorbate 20 or its variants significantly increased relative span and vol. % of droplets with sizes less than 105 μm . The inclusion of suitable DRT reversed this effect, resulting in statistically significant decreases in relative span and vol. % of droplets with sizes less than 105 μm .

BIOLOGICAL PROPERTIES

Polysorbate 23 significantly increased glyphosate control of common waterhemp at early observation intervals and provided greater control than polysorbate 20 at both 7 and 28 days after treatment (Table 8).

FIG. 8 Differences in imidacloprid uptake through isolated leaf cuticles for polysorbate 20 variants. Measured uptake was statistically equivalent to polysorbate 20.

% Uptake of Imidacloprid @ 72 hr determined by HPLC

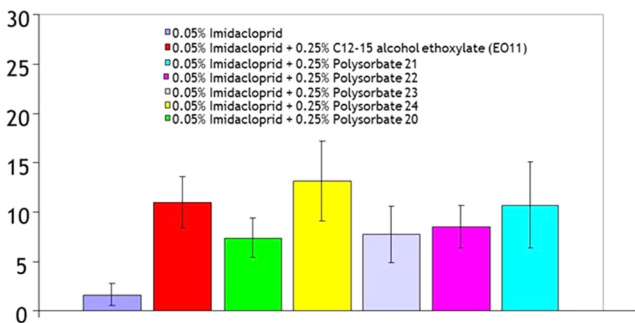


TABLE 7 Droplet size characterization for all treatments containing 1.7% (v/v) RoundUp PowerMAX[®] and 2.5% (w/w) ammonium sulfate. Percent change <105 microns describes change in volume of droplets observed below this value relative to control containing only RoundUp PowerMAX and ammonium sulfate. RoundUp PowerMAX[®] is a trademark of Monsanto.

Adjuvant Treatment (0.25 % in XR11004 (40 psi))	Dv10		Dv50		Relative Span		Percent < 105 μm	
	μm		μm					
70 % Polysorbate 20 with 30 % DRT	113	(2)a	230	(2)cde	1.23	ijk	−34.0 %	k
70 % Polysorbate 24 with 30 % DRT	121	uv	236	x-b	1.17	l-p	−48.7 %	pqr
70 % Polysorbate 23 with 30 % DRT	129	n-q	246	m-t	1.11	r-a	−59.8 %	v-a
70 % Polysorbate 22 with 30 % DRT	130	m-q	247	k-s	1.11	r-z	−60.3 %	w-b
70 % Polysorbate 21 with 30 % DRT	131	k-n	249	h-p	1.09	t-c	−62.1 %	x-d
100 % Polysorbate 20	91	(2)hi	211	(2)jkl	1.44	a	15.0 %	ab
100 % Polysorbate 24	91	(2)hi	211	(2)jkl	1.43	ab	15.7 %	ab
100 % Polysorbate 23	92	(2)hi	212	(2)jkl	1.42	abc	13.4 %	abc
100 % Polysorbate 22	95	(2)efg	210	(2)kl	1.36	def	5.7 %	de
100 % Polysorbate 21	108	(2)b	226	(2)ef	1.26	hi	−25.0 %	ij
1.7 % RoundUp™ PowerMax + 2.5 % AMS	97	(2)e	218	(2)hi	1.34	ef	0.0 %	f

TABLE 8 Comparative glyphosate (0.375 lb ae/A) control of grass and broadleaf weeds with no adjuvant, NIS control, polysorbate 20, and polysorbate 23 (0.25 % v/v). DAT is days after treatment. Color and lettering associated with tabulated numeric values relate to statistical significance as explained in [Table 2](#).

Treatment	Giant Foxtail		Common Waterhemp		Ivyleaf Morningglory		Cocklebur	
	7 DAT	28 DAT	7 DAT	28 DAT	7 DAT	28 DAT	7 DAT	28 DAT
Polysorbate 20	99 a	99 a	83 bc	89 bcd	35 a	61 a	99 a	99 a
NIS (NP9 + Fatty Acid)	99 a	99 a	68 g-k	87 b-e	30 a-d	60 a	98 a	99 a
Polysorbate 23	98 ab	98 ab	87 ab	94 ab	33 ab	62 a	99 a	99 a
No adjuvant	92 e	95 d	60 kl	83 de	20 e	53 a	98 a	99 a
Least significant difference (LSD) ($P=0.05$)	2.2	1.8	9.1	7.1	5.5	13.6	1	0

TABLE 9 Comparative paraquat (0.0078 lb ai/A) control of giant ragweed with no adjuvant, NIS control, polysorbate 20, and polysorbate 23 (0.25 % v/v). DAT is days after treatment. Color and lettering associated with tabulated numeric values relate to statistical significance as explained in [Table 2](#).

Treatment	Giant Ragweed	
	4 DAT	10 DAT
No adjuvant	66.8 f-m	46 a-d
NIS (NP9 + Fatty Acid)	60 r-u	40.8 c-n
Polysorbate 23	77.5 a	44.5 a-h
Polysorbate 20	76.3 ab	47.5 a
LSD ($P=0.05$)	4.72	5.79

Polysorbate 23 significantly increased glyphosate control of giant ragweed at 4 days after treatment and provided greater control at 10 days after treatment than the control NIS adjuvant ([Table 9](#)). Polysorbate 20 significantly increased glyphosate control of giant ragweed at 4 and 10 days after treatment than the control NIS adjuvant ([Table 9](#)).

Polysorbates 21 and 22 significantly increased saflufenacil control of marestalk at 3 and 7 days after treatment and provided equivalent control at 14 days after treatment in comparison to polysorbate 20 ([Table 10](#)).

FIG. 9 Response surface graph for glyphosate and clethodim tank mixture control of glyphosate tolerant corn with polysorbate 20 and variants, each applied at 0.0625, 0.125, and 0.25 vol. %. Polysorbate 20 variant identity in relation to ethoxylation degree appears in [Table 1](#).

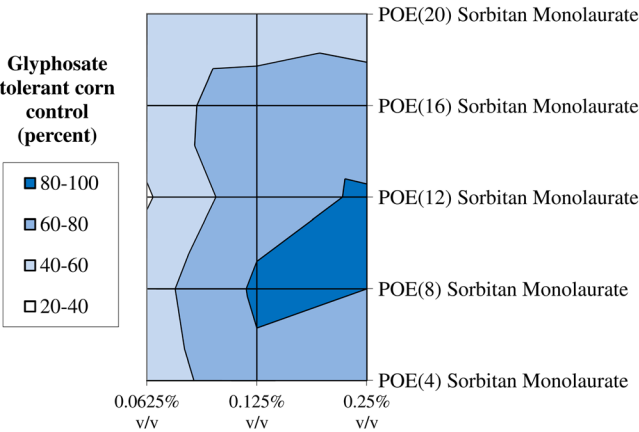


TABLE 10 Comparative saflufenacil (0.025 fluid oz/A) control of marestalk with untreated control, polysorbate 20, and polysorbate 20 variants (0.25 vol. %). DAT is days after treatment. Color and lettering associated with tabulated numeric values relate to statistical significance as explained in [Table 2](#).

Treatment	Marestalk		
	3 DAT	7 DAT	14 DAT
Untreated	0 k	0 h	0 j
Polysorbate 20	63.1 ij	68.8 fg	50.6 c-i
Polysorbate 21	84.8 bcd	83.8 bcd	70 abc
Polysorbate 22	77.5 def	83 bcd	68.3 a-d
Polysorbate 23	72.3 e-i	78.4 c-f	59.8 b-g
Polysorbate 24	66.8 hij	68.6 fg	53.8 b-i
LSD (P = .05)	5.64	6.5	11.5

Polysorbate 22 and polysorbate 23 applied at rates between 0.125 and 0.25 % by volume significantly increased clethodim and glyphosate tank mixture control of volunteer corn ([Fig. 9](#)). The increased response appears as the dark region in the graphic where control is between 80 and 100 % at a polysorbate 22 (having 8 mols of ethoxylation) use rate of 0.125 to 0.25 vol. % or a polysorbate 23 (having 12 mols of ethoxylation) use rate of 0.25 vol. %.

Conclusions

In continuation of work described at the International Symposium on Adjuvants for Agrochemicals (ISAA) in 2010, development included systematic investigation into elements of polysorbate 20 composition that provided opportunities to enhance its adjuvant performance, both physically and biologically, while retaining its principal biological and toxicological benefits including its broad acceptability in food, pharmaceuticals, and pesticides. Targeted variants were made successfully and both properties and characterization aligned. NMR and MALDI confirmed material identity as ethoxylated sorbitan monolaurate. Chemical properties and molecular fingerprinting results were in line with expectation, while predicted values for selected specifications aligned with measured values. Variations in composition resulted in changed physical behavior where observed surfactancy aligned with structural changes. Herbicide adjuvancy was consistent with or somewhat better than polysorbate 20 in certain cases, imidacloprid uptake remained enhanced, glyphosate tolerant corn control by clethodim and glyphosate tank mixtures was improved, and glyphosate antagonism of annual grass control by clethodim was mitigated with high levels of broadleaf control.

With all materials conforming to the chemical definition of polyoxyethylene sorbitan monolaurate [5] (effectively the same chemical identity as polysorbate 20), it was concluded that this development would have a desirable fit for expanded use

of polysorbate 20 variants in materials destined for registration as either biopesticides and specifically that would be suitable for use in organic agricultural commodity production (National Organic Program (“NOP Compliant”) as per US regulations) [13]. Important attributes available to formulators associated with the use of polysorbate 20 and its variants includes their conformance to FDA Food Additive clearances [13], EPA Design for the Environment standards [14], and JECFA/WHO FAO amenability [8]. These aspects build on over 50 years of positive agricultural experience established for polysorbate 20 (Tween 20) as outlined and referenced at ISAA in 2010 [2].

In addition to the areas described above, further applications would exist in products targeted at ecologically sensitive niches such as aquatic use pesticides, biological control agents, or products that are labelled for use near surface water. Considered as a list of attributes and properties, the polysorbate 20 variants described in this research offer:

- The ecological and toxicological benefits of polysorbate 20 with an expanded range of performance options.
- Uniform identity facilitating early registration of a single substance with an option to implement changes for improved stability or biological performance.
- Access to a range of design for environment (DfE) listed polysorbates enabling nonyl phenol ethoxylates (NPE) replacement with preferred NIS chemistry; no “dead fish, dead tree” label.
- NOP compliant options with single chemical identity as defined by Chemical Abstracts Service (CAS) number and chemical name.
- Enhanced surface activity to provide better wetting, lower equilibrium surface tension (EST), lower contact angle than polysorbate 20.
- Different hydrophile-lipophile balance (HLB), critical micelle concentration (CMC), and micellar lifetimes offering varied adjuvant performance.
- Altered spray retention and deposit formation thereby providing different deposition, humectancy, surface area, and drying rates.
- Differentiated effects on spray droplet spectrum and spray quality.

The range of targeted structural and functional changes may more effectively facilitate NPE replacement in a range of crop oil concentrate (COC), methylated seed oil (MSO), and NIS adjuvants as they provide a broader spectrum of performance where improved surface activity and adjuvancy is required from the chemistry selected along with minimizing potential negative health or environmental impact.

ACKNOWLEDGMENTS

Special thanks are offered to Joe Matthews, Wayne Jackson, Hannah Griffiths, Kathryn Knight, Vincent Thomas, and Erik Gunderman for their fundamental contributions.

References

- [1] Smith, L. W. and Foy, C. L., “Interactions of Several Paraquat-Surfactant Mixtures,” *Weeds*, Vol. 15, No. 1, 1967, pp. 67–72.

- [2] Thomas, V. and Lindner, G. J., "Role of Polyoxyethylene (20) Sorbitan Monolaurate (Tween 20) in Agrochemical Preparations," *Proceedings of the 9th International Symposium on Adjuvants for Agrochemicals (ISAA 2010)*, P. Baur, Ed., ISAA Society, Amsterdam, 2010, pp. 121-138.
- [3] BIBRA, *BIBRA Toxicity Profile, Polysorbate 20*, BIBRA Toxicology International, Surrey, UK, 1989.
- [4] CIREP, "Final Report on the Safety Assessment of Polysorbate 20, 21, 40, 60, 61 65, 80, 81 and 85," *J. Am. College Toxicol.*, Vol. 3, 1984, pp. 1-82.
- [5] EPA OPP, Action Memorandum: Inert Reassessment—Members of the Sorbitan Fatty Acid Esters and the Polysorbates, EPA, Washington, D.C., 2005.
- [6] Federal Environmental Agency, Germany, "Classification of Substances and Mixtures Into Water Hazard Classes According to the Administrative Regulation on the Classification of Substances Hazardous to Waters," *Verwaltungsvorschrift wassergefährdende Stoffe; VwVwS*, UBA, Dessau-Roßlau, Germany, 1999.
- [7] Federal Environmental Agency, Germany, "List of Substances Hazardous to Waters Classified Into Water Hazard Classes 1 to 3. In Annex 2 of the Administrative Regulation on the Classification of Substances Hazardous to Waters," *Verwaltungsvorschrift wassergefährdende Stoffe; VwVwS*, UBA, Dessau-Roßlau, Germany, 2005.
- [8] JECFA, "Polyoxyethylene (20) Sorbitan Monoesters of Lauric, Oleic, Palmitic, and Stearic Acid and Triester of Stearic Acid," *Report Series No. 539, WHO Food Additives Series 5, Monograph 304*, JECFA/FAO, Rome, Italy, 1974.
- [9] Griffin, W. C., "Classification of Surface-Active Agents by HLB," *J. Soc. Cosmet. Chem.*, Vol. 1, 1949, pp. 311-325.
- [10] Brander, J. D., "The Composition of NF-Defined Emulsifiers: Sorbitan Monolaurate, Monopalmitate, Monostearate, Monooleate, Polysorbate 20, Polysorbate 40, Polysorbate 60, and Polysorbate 80," *Drug Develop. Ind. Pharm.*, Vol. 24, No. 11, 1998, pp. 1049-1054.
- [11] Schönherr, J. and Riederer, M., "Plant Cuticles and Lipophilic Compounds During Enzymic Isolation," *Plant, Cell, Environ.*, Vol. 9, No. 6, 1986, pp. 459-466.
- [12] ASTM E2798-11: Standard Test Method for Characterization of Performance of Pesticide Spray Drift Reduction Adjuvants for Ground Application, ASTM International, West Conshohocken, PA, 2011, www.astm.org.
- [13] Schwarz, E. G. and Reid, W. G., "Surface Active Agents—Their Behavior and Industrial Use," *Ind. Eng. Chem.*, Vol. 56, No. 9, 1964, pp. 26-31.
- [14] Lindner, G. J. and Kaziska, A., "Historical Survey on Ecolabeling Efforts and Criteria for Green Inert or Other Ingredients: EPA Design for the Environment," *J. ASTM Int.*, Vol. 9, No. 3, 2012, pp. 1-13.
- [15] Food and Drug Administration, *Food and Drugs. Electronic Code of Federal Regulations, Title 21*, Food and Drug Administration, US Government Printing Office, Washington, D.C., 2009.