Supplementary Information

Grain size modulates volcanic ash retention on crop foliage and potential yield loss

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Material and methods

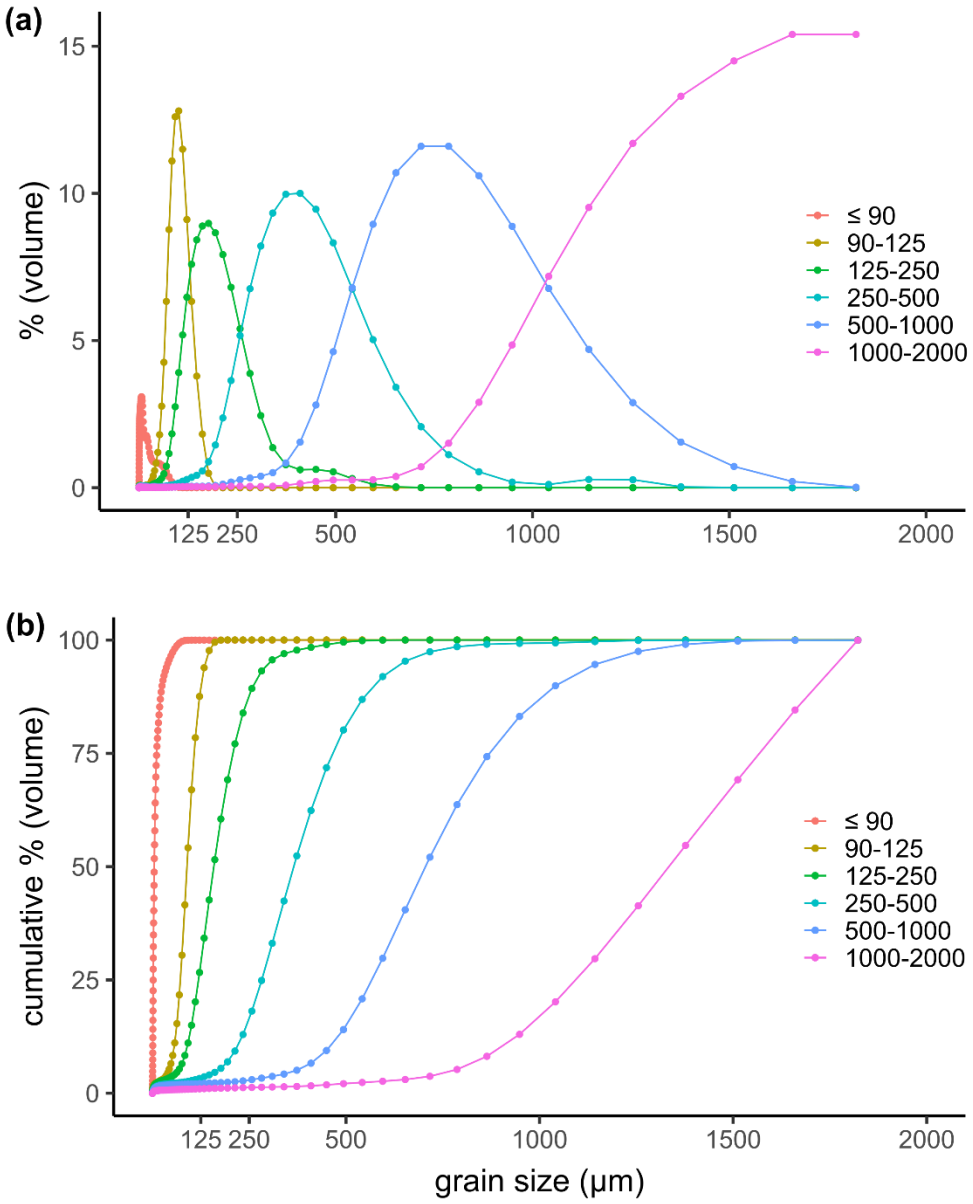

Figure S1: Grain size characteristics of the six ash size ranges (≤ 90, 90-125, 125-250, 250-500, 500-1000, 1000-2000 µm) used for simulating ash fall on tomato and chilli pepper plants: distributions (a) and cumulative distributions (b).

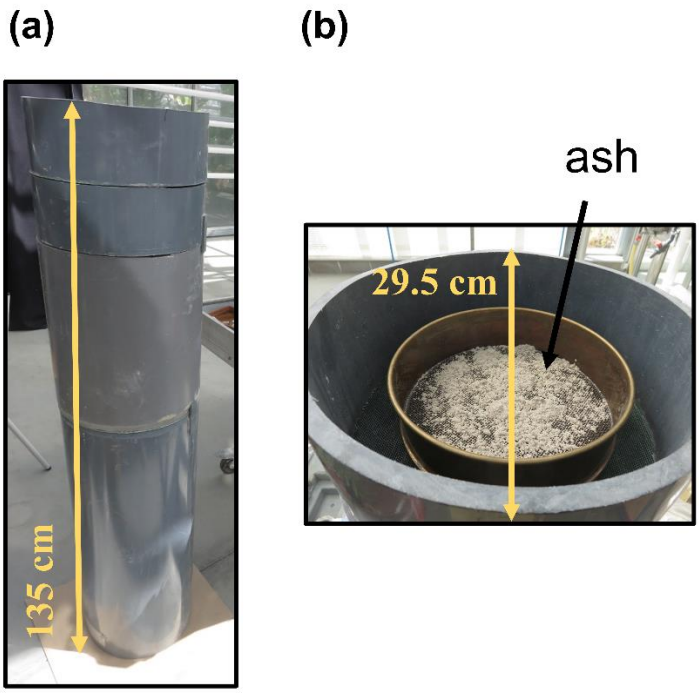

Figure S2: Photos of the ash fall simulator used to apply ash on tomato and chilli pepper plants. The device consists of *PVC* tube with three 1-mm opening meshes placed at 75, 110 and 120 cm from the tube base: side view (a) and top view with ash introduced through a 2-cm mesh sieve (b).

Results

Table S1: Summary statistics (mean, standard deviation (*sd*), minimum (*min*) and maximum (*max*) value, first (*q1*) and third (*q3*) quartile) of the percentage of foliar cover of tomato and chilli pepper plants coated with ash. The results are shown for the six ash grain size ranges tested in dry and wet conditions at leaf surfaces.

ash size range (µm)	**foliar cover coated with ash (%)**						
	mean	***sd***	***min***	***max***	**median**	***q1***	***q3***
tomato							
dry							
< 90	88	5	79	99	86	85	92
90-125	48	13	26	64	49	38	58
125-250	44	14	12	68	43	37	54
250-500	20	9	5	38	17	13	27
500-1000	5	5	0	16	5	2	7
1000-2000	4	7	0	26	1	0	6
wet							
< 90	87	8	67	97	88	85	92
90-125	60	14	30	77	62	57	70
125-250	67	9	53	86	66	61	73
250-500	37	10	17	52	40	29	44
500-1000	13	8	6	39	12	9	15
1000-2000	5	6	0	22	3	0	6
chilli pepper							
dry							
< 90	89	3	83	93	90	86	92
90-125	41	9	29	60	40	35	44
125-250	14	6	6	27	13	10	19
250-500	2	2	0	7	3	1	3
500-1000	1	1	0	4	1	1	2
1000-2000	1	1	0	2	0	0	1
wet							
< 90	92	5	78	96	93	92	95
90-125	67	14	40	85	69	55	79
125-250	58	15	35	78	59	44	72
250-500	27	14	0	46	27	17	40
500-1000	9	4	3	14	8	5	12
1000-2000	2	1	0	3	2	1	3

Table S2: Treatments significantly different according to the Tukey (*HSD*) test with the difference between group means and the associate adjusted *p*-value (*p.adj*). The test was performed to evaluate the effect of (i) humidity conditions at leaf surfaces for tomato and chilli pepper plants and (ii) crop type in dry leaf conditions on the percentage of foliar cover coated with ash. “125”, “250” and “500” stand for the 90-125, 125-250 and 250-500 µm ash size ranges, respectively.

	% difference in mean foliar cover coated with ash	***p.adj***
Effect of humidity conditions		
125:tomato:dry-125:tomato:wet	-12.2	0.0366
250:tomato:dry-250:tomato:wet	-23.5	0.0000
500:tomato:dry-500:tomato:wet	-16.7	0.0001
mean ± sd	-17 ± 6	
125:chilli pepper:dry-125:chilli pepper:wet	-26.2	0.0000
250:chilli pepper:dry-250:chilli pepper:wet	-43.5	0.0000
500:chilli pepper:dry-500:chilli pepper:wet	-24.7	0.0000
mean ± sd	-31 ± 10	
Effect of crop type in dry conditions		
250:tomato:dry-250:chilli pepper:dry	29.2	0.0000
500:tomato:dry-500:chilli pepper:dry	17.8	0.0000

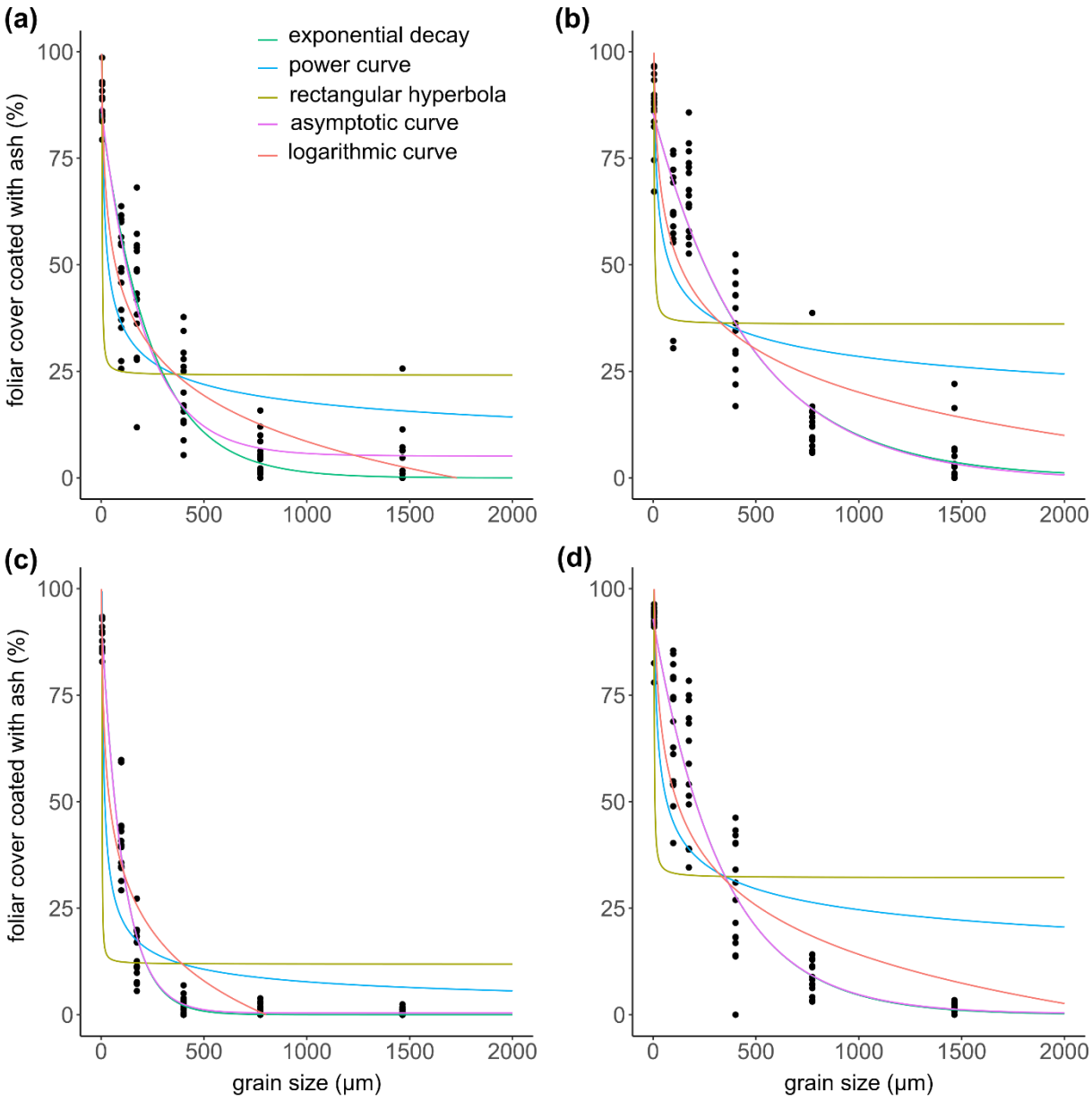

Figure S3: Fitting of the experimental datasets to represent the relationship between the percentage of foliar cover coated with ash and ash median grain size for tomato in dry (a) and wet (b) leaf conditions and chilli pepper in dry (c) and wet (d) leaf conditions. Five convex models were tested: exponential decay, power curve, rectangular hyperbola, asymptotic curve and logarithmic curve.

Table S3: Lack-of-fit analysis (F* statistics and corresponding *p*-values) of the five convex models (exponential decay, power curve, rectangular hyperbola, asymptotic curve and logarithmic curve) used to fit the four experimental datasets obtained by exposing tomato and chilli pepper in dry and wet leaf conditions to ash varying in grain size (see Fig. S3).

Model fitted (number of parameters)	***R* function used**	**F***				***p*-value**			
		tomato		**chilli pepper**		**tomato**		**chilli pepper**	
		dry	**wet**	**dry**	**wet**	**dry**	**wet**	**dry**	**wet**
exponential decay (2)	NLS.expodecay	0.378	0.120	0.009	0.002	0.8238	0.9750	0.9998	1.0000
power curve (2)	NLS.powerCurve	1.636	0.801	0.145	0.205	0.1723	0.5278	0.9648	0.9350
rectangular hyperbola (2)	Ssmicmen	3.950	1.439	0.307	0.399	0.0054	0.2278	0.8726	0.8089
asymptotic (3)	NLS.asymReg	0.405	0.159	0.011	0.003	0.7498	0.9236	0.9984	0.9998
logarithmic (2)	NLS.logCurve	0.438	0.532	0.078	0.106	0.7808	0.7125	0.9888	0.9801

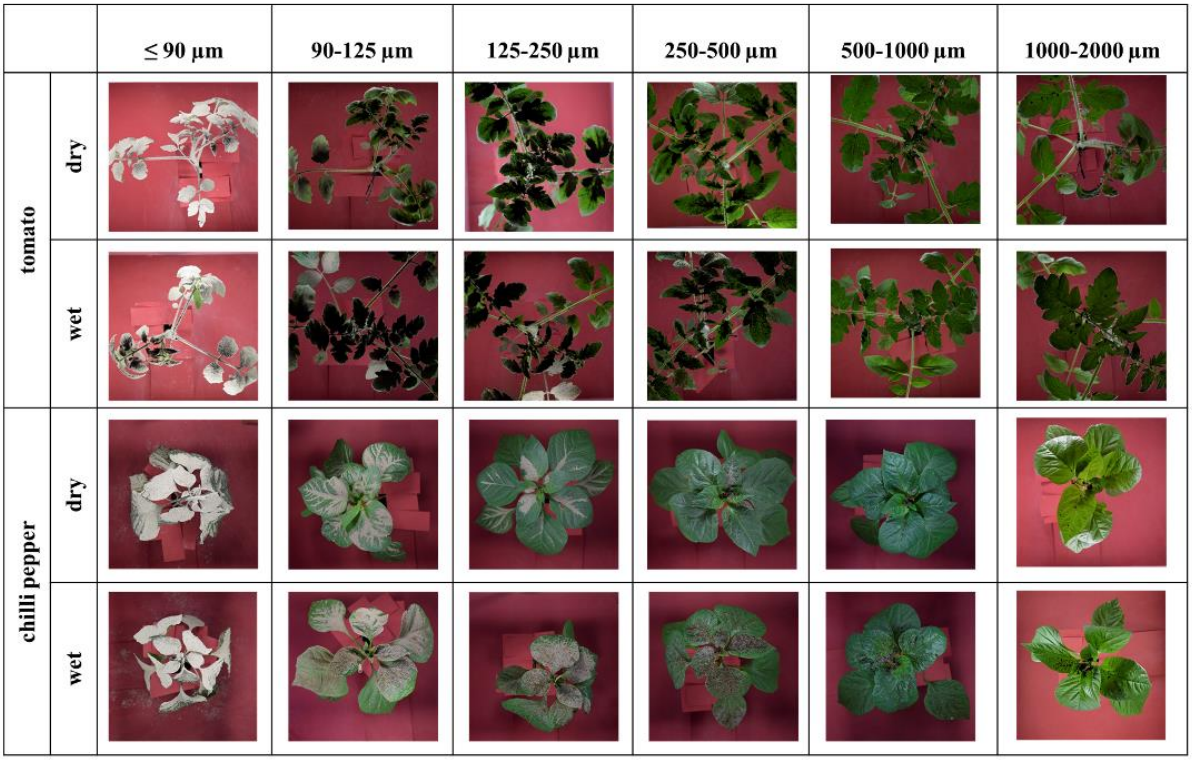

Figure S4: Photos of the tomato and chilli pepper plants after exposure to ash in dry and wet conditions at leaf surfaces. The columns correspond to the six ash size ranges tested (≤ 90, 90-125, 125-250, 250-500, 500-1000, 1000-2000 µm).

Discussion

Table S4: Terminal fall velocity of individual particles of 10, 100, 170, 410, 710 and 1470 µm as calculated using the drag model of Bagheri and Bonadonna (2016). The particles are non-spherical (flatness = 0.7, elongation = 0.7) and have a density of 2.54 g m^{-3}.

size (µm)	**terminal fall velocity ($m\ s^{-1}$)**
10	0
100	0.51
170	1.14
410	2.93
770	5.13
1470	7.96

Table S5: Parameter values used in the simulation of potential yield loss for tomato and chilli pepper plants exposed to ash. *k:* light interception coefficient; *Q:* incident radiation; *RUE:* radiation use efficiency; *CBP*: canopy partitioning factor; *ILAI*: proportion of *LAI* covered by ash and which does no operate photosynthesis; *DCB*: proportion of the biomass covered by ash which undergoes senescence; *TNL*: time needed for the plant to produce new leaves.

crop	growth cycle duration (days)	*k* ($MJ\ m^{-2}$leaf day^{-1})	*Q* ($MJ\ m^{-2}\ day^{-1}$)	*RUE* ($g\ MJ^{-1}$)	*CBP*	*ILAI*	*DCB*	*TNL* (days)
tomato	150	0.5	10.6	4.435	N(0.6,0.1)	N(0,1,1,0.4)	N(1,0.4)	N(0,30,0,10)
chilli pepper	250	0.8	10.6	3.4	N(0.6,0.1)	N(0,1,1,0.4)	N(1,0.4)	N(0,30,0,10)
source	/	tomato: Higashide et al. 2009; Farrokhi et al., 2021 chilli pepper: Surmaini et al., 2000; Ta et al., 2011	Solargis, 2022	tomato: Gallardo et al., 2014; Martínez-Ruiz et al., 2018 chilli pepper: Karam et al., 2009; Yildirim et al., 2017				

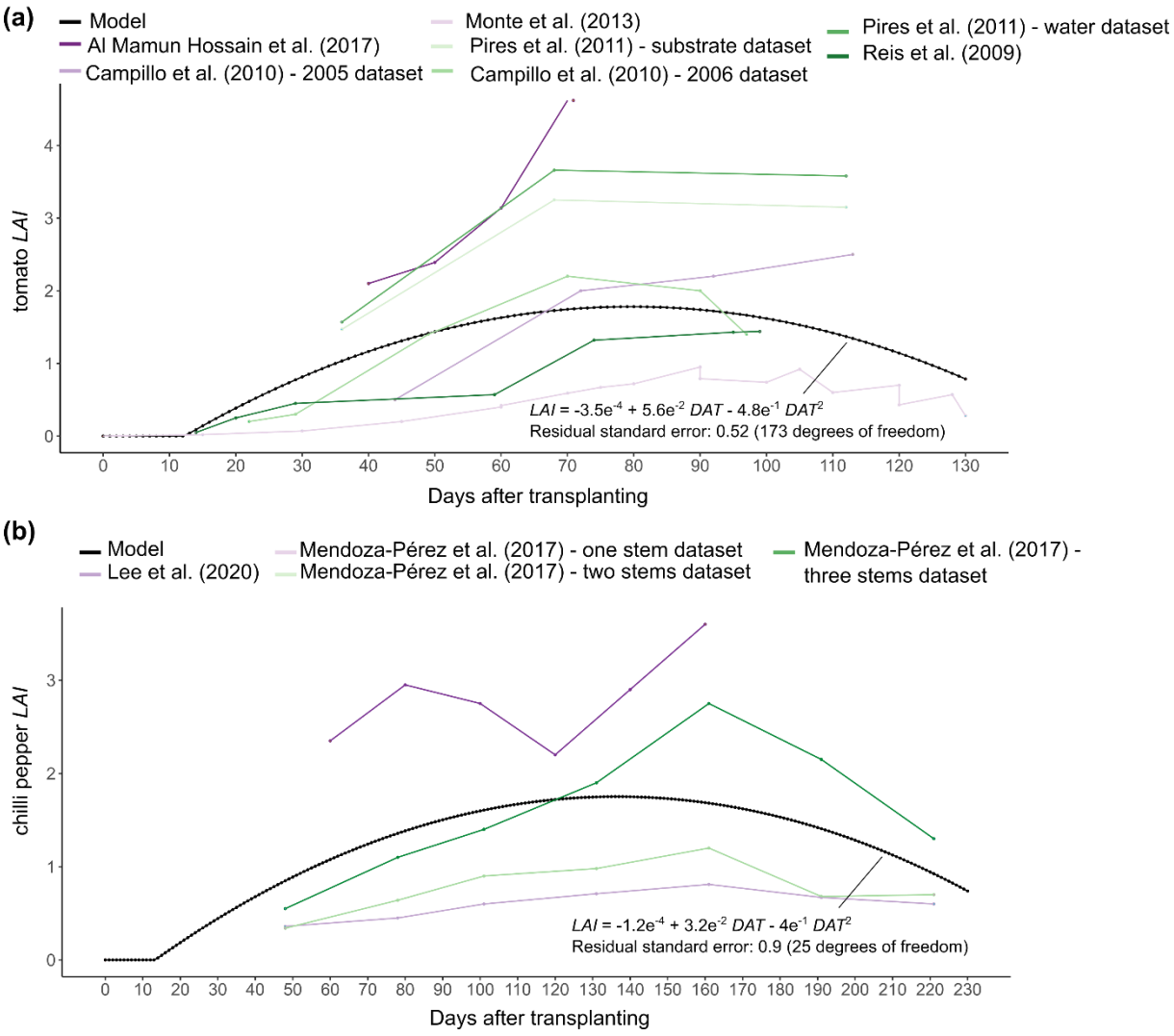

Figure S5: Temporal evolution of the leaf area index (*LAI*) for tomato (a) and chilli pepper (b) plants as modelled by fitting various datasets reported in the scientific literature. The *aomisc* package in *R* (Onofri, 2020) was used to obtain the best fit. Transplanting of tomato and chili pepper was assumed to take place 30 days after sowing. DAT refers to day after transplanting.

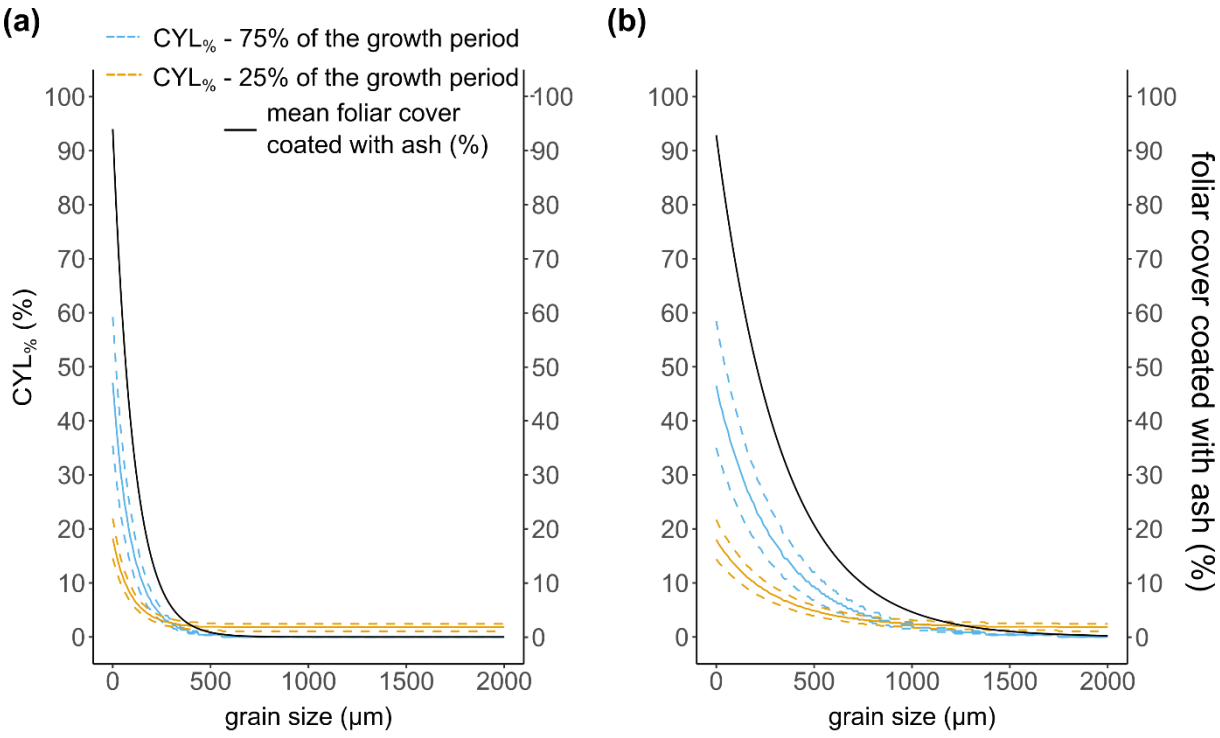

Figure S6: Potential crop yield loss (*CYL%*, first quartile, median and third quartile) estimated for chilli pepper plant as a function of ash grain size in dry (a) and wet (b) conditions at leaf surfaces.

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