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Sensitivity of littleseed canary grass populations from Punjab, India, to clodinafop-propargyl and isoproturon

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Abstract

Littleseed canary grass (*Phalaris minor* Retz.) is one of the most prevalent and troublesome annual grass weed species in wheat across the Indo-Gangetic plains (IGP) of India, including Punjab. Littleseed canary grass has evolved resistance to different herbicide sites of action in the IGP region. A targeted field survey was conducted in 2018 and 2019 for seed collection of littleseed canary grass populations (total 94) across different districts of Punjab state prior to wheat harvest. The main objective of this research was to characterize the sensitivity response of collected littleseed canary grass populations to clodinafop-propargyl (CP) and isoproturon (IPU) herbicides in whole-plant dose-response assays. Among all tested populations, 68 were found to be highly sensitive to CP, whereas all 94 populations were sensitive to IPU. Based on a 50% reduction in shoot dry biomass (GR_{50} values) and estimated sensitivity index (SI), 26 populations exhibited reduced sensitivity (SI of 2.2–4.4) to CP herbicide. The results also revealed that the littleseed canary grass populations with reduced sensitivity (SI ≥ 2.2) to CP had high sensitivity to IPU herbicide. Overall, these results suggested a high prevalence of littleseed canary grass populations with reduced sensitivity to CP herbicide in Punjab state. Diversified weed management strategies, including the use of alternative herbicides (both preemergence and postemergence), cultural (no-till drill for wheat sowing and narrow row spacing), and mechanical (cutting of littleseed canary grass panicles prior to wheat harvest) practices should be adopted to control littleseed canary grass populations with reduced sensitivity to CP.

1 | INTRODUCTION

Wheat (*Triticum aestivum* L.) is a predominant cereal crop grown in rotation with rice (*Oryza sativa* L.) in the Indo-Gangetic Plains (IGP) of India, including Punjab state (Malik et al., 1995). Weed infestations are a serious challenge to the successful production of wheat (Chhokar et al., 2006; Pandey et al., 1997). Littleseed canary grass (*Phalaris minor* Retz.) is one of the most troublesome winter annual grass weed species of wheat in a rice–wheat rotation (Chhokar & Malik, 2002; Chhokar et al., 2008; S. Singh et al., 1995). It was originally a native to the Mediterranean region and likely reached India

Abbreviations: CP, clodinafop-propargyl; IGP, Indo-Gangetic plains; IPU, isoproturon; SI, sensitivity index.

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through the import of Mexican wheat (Chhokar et al., 2008; S. Singh et al., 1995). The high infestation of littleseed canary grass under a rice–wheat rotation is due to its hard seed coat, which is known to tolerate oxygen stress under puddled conditions of rice cultivation. A possible reason for this oxygen stress tolerance is the formation of chemical metabolites and changes in membrane permeability (Parashar & Singh, 1985; S. Singh et al., 1995). Littleseed canary grass seeds remain dormant for a few months after maturity and can tolerate anaerobic conditions for up to 1 year as they enter secondary dormancy (Yadav & Malik, 2005). Deep placement of littleseed canary seeds in standing water in puddles transplanted rice fields disrupts seed susceptibility to solarization (Malik & Singh, 1995).

Littleseed canary grass has become more prevalent in wheat due to its similar morphology (self-pollinated with a C_3 photosynthetic pathway) and growing requirements (S. Singh et al., 1999) as the crop. Similar to wheat, a large proportion of littleseed canary grass seedbank germinates between 10 and 25°C (17–21°C being an optimal temperature range for germination) during mid-November to mid-December, and germination can last up to a 12-week period (U. S. Walia & Gill, 1995). Littleseed canary grass generally produce more tillers per plant than wheat under non-competitive conditions that eventually result in greater seed production, that is, 300–450 seeds per panicle (S. Singh et al., 1999). A season-long infestation of littleseed canary grass can reduce wheat yield by up to 80% depending on weed population density, cultivation practices, and soil and environmental factors (Kaur et al., 2021; Malik & Singh, 1995; S. Singh et al., 1995). Khera et al. (1995) and S. Singh and Malik (1994) reported that season-long competition with 50–500 littleseed canary m^{-2} resulted in 8%–50% wheat yield reduction, respectively.

The initial period of 4–6 weeks following wheat sowing is the most critical period for crop–weed competition and necessitates the need for weed control during this period (Chhokar et al., 2009; S. Singh et al., 1999). Broad-spectrum herbicides such as isoproturon (IPU) [N-4-isopropylphenyl-N,N-dimethylurea], metoxuron [N'-(3-chloro-4-methoxyphenyl)-N,N-dimethylurea], chlortoluron [N′-(3-Chloro-4-methylphenyl)-N,N-dimethylurea], and methabenzthiauron [1-(1,3-benzothiazol-2-yl)−1,3-dimethylurea] were generally used for weed control in wheat during the mid-1970s (Bhullar et al., 2017). These broad-spectrum herbicides (especially IPU) were proven to be highly effective against littleseed canary grass in wheat (Malik et al., 1995). Consequently, wheat producers readily adopted IPU herbicide (photosystem II inhibitor; WSSA group 7) in the 1980s due to its cost-effectiveness, convenience to apply, broad-spectrum weed control, and wide application window (Chhokar et al., 2009; Malik & Singh, 1993). However, the overreliance and continuous use of IPU herbicide for weed control in wheat fields led to the evolution of resistance in littleseed canary grass in the early 1990s in Haryana (Malik & Singh, 1993) and later in Punjab (S. S. Walia et al., 1997). This was the first case of herbicide resistance reported in India (Malik & Singh, 1993, 1995), and it was the first global case of any weed resistance to IPU (Bhullar et al., 2017). The spread of IPU-resistant littleseed canary grass was estimated to be 0.8–1.0 million ha in northwestern India by 1993, and the highest affected areas were reported in Haryana (0.56–0.6 m ha) followed by Punjab (0.3 m ha) (Franke, 2002; R. Singh et al., 2021). During the early years of IPU resistance, several reports of complete wheat crop failure in farmers' fields with a heavy infestation of littleseed canary grass (2000–3000 plants m^{-2}) were documented (Malik & Singh, 1995). IPU-resistant littleseed canary grass populations required 3–15 times more IPU herbicide rates for effective control (Malik et al., 1995).

In 1995, clodinafop-propargyl (CP) [propyny(R)-2-[4-[(5-chloro-3-fluoro-2-pyridinyl)oxy] phenoxy] propionate], sulfosulfuron [N-[(4,6-dimethoxypyrimidin-2-yl)carbamoyl]-2-(ethanesulfonyl)imidazo[1,2-a]pyridine-3-sulfonamide], and fenoxaprop [2[4-[(6-chloro-2-benzoxazolyl)oxy]-phenoxy]-propanoic acid] were introduced as alternative herbicides to control IPU-resistant littleseed canary grass in wheat (Yadav & Malik, 2005). However, within 5–6 years of introduction, a high level of cross-resistance to fenoxaprop and CP (acetyl-CoA-carboxylase [ACCase] inhibitor; WSSA group 1) was observed in littleseed canary grass populations in wheat fields in Haryana (Chhokar & Sharma, 2008). Littleseed canary grass with multiple resistance to fenoxaprop, CP, sulfosulfuron, and/or pinoxaden [[8-(2,6-diethyl-4-methylphenyl)-7-oxo-1,2,4,5-tetrahydropyrazolo[1,2-d][1,4,5]oxadiazepin-9-yl] 2, 2-dimethylpropanoate] has also been reported previously in Punjab (Bhullar et al., 2002, 2014; Heap, 2022; Kaur et al., 2015).

Resistance to CP has previously been documented in several littleseed canary grass populations from Punjab and Haryana (Das et al., 2013). However, producers in Punjab still rely on CP and IPU herbicides for grass weed control in wheat. To preserve these herbicides for future use, proactive

Core Ideas

- Sensitivity of littleseed canary grass populations (total 94) from Punjab, India, to clodinafop-propargyl and isoproturon was investigated.
- About 28% of the populations exhibited reduced sensitivity (sensitivity index of 2.2–4.4) to clodinafop-propargy herbicide.
- All populations showed high sensitivity to isoproturon herbicide (sensitivity index < 2.0).

management strategies are needed to delay the evolution of herbicide resistance in weed species (Norsworthy et al., 2012). Therefore, it is important to monitor the sensitivity of problematic grass weed populations to the CP and IPU over a wide geography. This state-wide surveillance of littleseed canary grass populations from wheat-producing areas in Punjab will allow assessment of future populations shifts in response to different use patterns of CP and IPU (Crespo et al., 2016; Moss, 2001). The information will also help to develop and implement effective and alternative littleseed canary grass control strategies. Therefore, the main objective of this research was to characterize the sensitivity response of littleseed canary grass populations collected from 94 different wheat fields across Punjab state to CP and IPU herbicides in whole plant dose-response assays.

2 | MATERIALS AND METHODS

2.1 | Plant material

Littleseed canary grass control failures after herbicide application(s) were previously reported by wheat producers from 14 different districts of Punjab state in India. Targeted field surveys for the collection of littleseed canary grass seeds were conducted in the spring (prior to wheat harvest) of 2018 and 2019 across 14 districts (Amritsar, Barnala, Ferozepur, Gurdaspur, Hoshiarpur, Jalandhar, Kapurthala, Ludhiana, Moga, Patiala, Ropar, Sangrur, Tarantaran, and Fategarh Sahib) of Punjab state. Seeds of littleseed canary grass were collected from an area of ~100 m wide by 100 m long in each of the selected field site. The global positioning system coordinates for each collection site were recorded (Table 1). Physiologically matured seed heads of littleseed canary grass populations (one population per field) surviving/escaping postemergence herbicide applications were collected from wheat fields prior to crop harvest in the first fortnight of April. Seeds were collected from 94 different field locations (the collection of about 80–100 seed heads per location was considered a population) across the state (Table 1). The majority of those fields were under a rice–wheat rotation with a history of littleseed canary grass infestation. However, information on herbicide use patterns in those fields was not known. In addition, seeds of two littleseed canary grass populations (SJ and SU) that had not previously been exposed to any herbicide were also collected from wheat fields in Sujana district (Jammu and Kashmir state) and Uchana town in Hisar district (Haryana state) and were used as "susceptible controls." The collected seed heads of littleseed canary grass populations were placed in paper bags, air dried at room temperature for 2 weeks, and then manually threshed. Threshed littleseed canary grass seed samples were cleaned by winnowing and using a 100-mesh sieve to get clean and matured seeds. The

TABLE 1 Locations of wheat field sites in various districts of Punjab state in northwestern India from where seeds of littleseed canary grass were collected in 2018 and 2019.

		GPS coordinates	
Population	District	Latitude	Longitude
T1	Tarantaran	31.24	74.60
T2	Tarantaran	31.24	74.60
T3	Tarantaran	31.24	74.61
T4	Tarantaran	31.24	74.60
A1	Amritsar	31.67	74.69
A2	Amritsar	31.75	74.84
A3	Amritsar	31.68	75.06
P1	Patiala	30.50	76.25
P2	Patiala	30.33	76.21
FS1	Fatehgarh Sahib	30.66	76.35
FS2	Fatehgarh Sahib	30.66	76.41
K1	Kapurthala	31.30	75.35
K2	Kapurthala	31.33	75.15
K3	Kapurthala	31.36	75.23
K4	Kapurthala	31.32	75.37
K5	Kapurthala	31.37	75.33
K6	Kapurthala	31.43	75.36
J1	Jalandhar	31.23	75.65
J2	Jalandhar	31.10	75.57
J3	Jalandhar	31.07	75.34
J4	Jalandhar	31.36	75.71
J5	Jalandhar	31.45	75.58
J6	Jalandhar	31.08	75.27
J7	Jalandhar	31.08	75.26
J8	Jalandhar	31.22	75.62
L1	Ludhiana	30.71	75.83
L2	Ludhiana	30.80	76.00
L3	Ludhiana	30.47	76.00
L4	Ludhiana	30.90	76.25
L5	Ludhiana	30.75	75.94
L6	Ludhiana	30.57	76.15
L7	Ludhiana	30.56	76.19
L8	Ludhiana	30.66	76.09
L9	Ludhiana	30.90	75.79
L10	Ludhiana	30.75	75.51
L11	Ludhiana	30.81	75.69
L12	Ludhiana	30.95	76.17
L13	Ludhiana	30.72	76.03
L14	Ludhiana	30.92	76.18
L15	Ludhiana	30.97	76.14
S1	Sangrur	29.94	75.80
S2	Sangrur	30.19	75.58
S3	Sangrur	30.52	75.89

(Continues)

TABLE 1 (Continued)

Population	District	GPS coordinates	
		Latitude	Longitude
S4	Sangrur	30.27	75.82
S5	Sangrur	30.40	75.95
S6	Sangrur	31.52	75.18
S7	Sangrur	30.20	75.51
S8	Sangrur	30.35	75.93
S9	Sangrur	30.19	75.58
S10	Sangrur	30.33	75.69
S11	Sangrur	30.29	75.96
S12	Sangrur	30.19	75.59
S13	Sangrur	30.38	75.54
S14	Sangrur	30.17	76.02
S15	Sangrur	30.16	76.02
S16	Sangrur	30.16	76.02
H1	Hoshiarpur	31.46	75.93
H2	Hoshiarpur	31.49	75.84
H3	Hoshiarpur	31.55	75.75
H4	Hoshiarpur	31.42	76.04
R1	Ropar	30.98	76.55
R2	Ropar	30.86	76.45
R3	Ropar	31.04	76.46
R4	Ropar	30.94	76.57
R5	Ropar	30.91	76.56
R6	Ropar	30.95	76.44
R7	Ropar	30.92	76.65
B1	Barnala	30.31	75.52
B2	Barnala	30.34	75.36
B3	Barnala	30.45	75.21
B4	Barnala	30.31	75.37
B5	Barnala	30.22	75.34
B6	Barnala	30.33	75.44
B7	Barnala	30.23	75.29
B8	Barnala	30.45	75.53
M1	Moga	30.70	75.19
M2	Moga	30.89	75.14
M3	Moga	30.49	75.21
M4	Moga	30.50	75.07
M5	Moga	30.67	75.21
M6	Moga	30.64	75.25
M7	Moga	30.60	75.04
F1	Ferozepur	31.05	74.87
F2	Ferozepur	31.09	74.57
F3	Ferozepur	30.85	74.78
F4	Ferozepur	30.87	74.76
F5	Ferozepur	30.47	74.24
F6	Ferozepur	30.45	76.22
F7	Ferozepur	30.46	76.24
F8	Ferozepur	30.93	74.68
G1	Gurdaspur	32.00	75.42
G2	Gurdaspur	32.01	75.02
G3	Gurdaspur	32.01	75.41
G4	Gurdaspur	31.98	75.13
G5	Gurdaspur	31.90	75.34

(Continues)

TABLE 1 (Continued)

Abbreviation: GPS, global positioning system.

cleaned seeds of each littleseed canary grass population were stored in sealed paper bags at 4°C until used in subsequent experiments.

2.2 | Whole plant dose-response assays

Seed viability of all collected littleseed canary grass populations was tested using a Petri plate method, where 10 seeds from each population were placed on moist filtered paper (Whatman Paper 2) and incubated at a constant temperature of 20°C with a 12-h photoperiod. The germinated seeds were counted 10 days after incubation. All littleseed canary grass populations exhibited >90% germination (data not shown) and were used for dose-response experiments. Experiments were conducted in October 2018 and repeated in November 2019 in an open area under natural conditions at the Department of Agronomy, Punjab Agricultural University, Ludhiana (30.902 N, 75.810 E), using plastic pots (15 cm diameter and 20 cm depth) containing field-collected soil. Soil was collected from research fields at Punjab Agricultural University with no prior infestation of littleseed canary grass. The collected field soil was finely ground and sieved to remove unwanted plant material. About 15 g of vermi-compost was added to every pot to provide the desired nutrition to the plants. Experiments were conducted in a randomized complete block design with four replications. Forty seeds from each selected population were sown in each pot at a 1.25-cm depth. Each pot was manually watered prior to seeding littleseed canary grass populations. Pots were covered with a black polythene sheet for 5 days to allow for a desired temperature for germination and protect the seeds from bird predation. After seedling emergence, plants were watered when needed to avoid moisture stress. At 7 days after emergence, littleseed canary grass seedlings were thinned, and 20 plants were retained in each pot for herbicide spray. At the two- to three-leaf stage (about 20 days after sowing), plants from each population were separately treated with Isoproturon (IPU; Isoguard 75 WP; Gharda Chemicals Pvt. Ltd.) at

the rate of 0 (nontreated), 234.5, 469, 938, 1876, and 3752 g a.i. ha^{-1} (where 938 g a.i. ha^{-1} represents the field-use rate of IPU for littleseed canary grass control in wheat) and CP (Topik 15 WP; Syngenta company) at 0 (nontreated), 15, 30, 60, 120, and 240 g a.i. ha^{-1} (where 60 g a.i. ha^{-1} represents the field-use rate of CP for littleseed canary grass control in wheat). All selected doses of IPU and CP were applied using a knapsack sprayer fitted with a flat fan nozzle (FFP/95/900 with pressure 2.8 kg cm^{-2}) calibrated to deliver 375 L ha^{-1} of spray solution. At 21 days after treatment, all littleseed canary grass plants (per pot basis) for each population and each tested herbicide dose were manually cut at the soil surface using a sickle, placed in paper bags, and dried in the sun for 7 days and then oven dried for 2 days at 60°C, and then weighed to obtain the aboveground shoot dry weights.

2.3 | Statistical analysis

For each herbicide, the aboveground shoot dry weight data for each population were converted to percent reduction in relation to the nontreated control. Data on percent shoot dry weight reduction were subjected to ANOVA using PROC MIXED in SAS (SAS v. 9.3, SAS Institute, Cary, NC, USA). Prior to analysis, data were tested for normality of residuals using the PROC UNIVARIATE procedure. Data on percentage shoot dry weight reduction were regressed against the herbicide rate with a four-parameter log-logistic model using the "*drc*" package in the R program (Ritz & Streibig, 2005). A lack-of-fit test ($p > 0.05$) indicated that the selected nonlinear model (Equation 1) accurately described the percent shoot dry weight reduction data for each tested population (Ritz & Streibig, 2005). The four-parameter log-logistic model corresponded to the following equation (Ritz et al., 2015):

$$y = c + \{d - c/1 + exp\,[b\,(log\,(x) - log\,(e))]\}, \quad (1)$$

where y represents the percent shoot dry weight reduction at a herbicide dose of x, b is the slope of each curve at e, d denotes the upper asymptote, c denotes the lower asymptote, and e denotes the effective dose of CP and/or IPU herbicide causing 50% reduction in shoot dry weight (GR_{50} values). The sensitivity index (SI), which is the ratio of the GR_{50} value of the selected littleseed canary grass population to the averaged GR_{50} value of the susceptible populations, was used to determine the sensitivity response of each population to CP and IPU herbicides. Based on the estimated SI values, all tested populations were categorized as either sensitive ($SI \leq 2$) or with reduced sensitivity ($SI > 2$) to IPU and CP herbicides.

3 | RESULTS AND DISCUSSION

3.1 | Sensitivity to CP

Results from whole plant dose-response assays indicated that both susceptible (SJ and SU) populations of littleseed canary grass were effectively controlled by CP. The SU and SJ populations only needed 25 and 26 g a.i. ha^{-1} of CP, respectively, to achieve a 50% reduction in shoot dry weight compared to the recommended use rate of 60 g a.i. ha^{-1} for CP (Table 2). The highest tested rate (240 g ha^{-1}) of CP resulted in complete mortality and maximum shoot dry weight reduction for all tested populations. About 72% of tested littleseed canary grass populations (out of a total 94 populations) showed high sensitivity to CP with sensitivity indices ranging from 0.8 to 2.0 (Table 2). The SI range did not exceed >2.0 among littleseed canary grass populations from Patiala, Hoshiarpur, Moga, and Ferozepur districts, and it varied from 1.4 to 1.6, 0.9 to 1.1, 0.9 to 1.5, and 1.0 to 2.0, respectively. In contrast, the sensitivity indices varied substantially among littleseed canary grass populations from Tarntaran, Fatehgarh Sahib, Jalandhar, Ludhiana, Ropar, Barnala, Gurdaspur, Amritsar, Kapurthala, and Sangrur districts with some populations showing SI range of 2.3–4.4 compared to both susceptible populations (Table 2). In contrast, Das et al. (2013) have previously reported 24 CP-resistant little seed canary grass populations from Punjab with resistance indices ranging from twofold to >10-fold. The majority of those CP-resistant populations were reported from Ludhiana, Patiala, Kapurthala, Sangrur, Muktsar, Nawanshahr, and Hoshiarpur.

Wheat producers from different districts of Punjab have been reporting poor performance of CP against littleseed canary grass. Repeated use of stand-alone CP herbicide is probably the main reason for the shift (R. Singh et al., 2021). In addition, this may also be due to differences in crop rotations, herbicide use patterns, and weather conditions among various districts of Punjab. For instance, many farmers in the region have historically relied on applying lower doses (half the recommended field dose) of CP herbicide at inappropriate timings for grass weed control in wheat (Das et al., 2013). Results from the current research clearly indicated that CP may no longer be an effective option for littleseed canary grass control in wheat in some areas of Amritsar, Barnala, Fatehgarh Sahib, Gurdaspur, Jalandhar, Kapurthala, Ludhiana, Ropar, and Sangrur districts of Punjab. Furthermore, continuous use of CP would probably lead to the spread of CP-resistant littleseed canary grass in larger areas through the dispersal of resistant seeds (Das et al., 2013). It has previously been reported that districts of Punjab with alternative

TABLE 2 Regression parameters (using Equation 1) for whole plant dose-response assays (at 21 days after treatment) on the basis of percent shoot dry weight reduction of littleseed canary grass populations from Punjab, India, treated with various rates of clodinafop-propargyl (0, 15, 30, 60, 120, and 240 g a.i. ha^{-1}) during 2018 and 2019.

	Regression parameters				
Population	**d (±SE)**	**c (±SE)**	**b (±SE)**	**GR_{50} (95% CI)[a]**	**SI_{50}[b]**
T1	101 (9.6)	1.3 (5.6)	−1.7 (0.4)	50 (33–67)	2.0
T2	97 (7.5)	1.4 (5.7)	−1.5 (0.5)	61 (18–104)	2.4
T3	102 (3.4)	0.1 (6.1)	−1.3 (0.4)	38 (16–60)	1.5
T4	101 (4.5)	0.7 (6.2)	−2.8 (0.7)	26 (21–31)	1.0
A1	103 (10.7)	0.3 (6.0)	−1.3 (0.6)	93 (11–175)	3.7
A2	106 (4.5)	0.3 (6.0)	−1.7 (0.5)	67 (36–98)	2.6
A3	96 (4.6)	5.0 (4.9)	−4.5 (1.8)	36 (29–43)	1.4
P1	90 (7.2)	0.4 (5.5)	−1.2 (0.4)	40 (5–75)	1.6
P2	96 (7.1)	3.9 (5.5)	−2.2 (0.6)	36 (25–47)	1.4
FS1	109 (7.5)	1.0 (3.6)	−1.3 (0.3)	80 (31–129)	3.2
FS2	100 (11.2)	1.6 (3.6)	−1.4 (0.3)	59 (33–85)	2.3
K1	94 (4.9)	0.0 (3.7)	−1.5 (0.4)	78 (35–121)	3.1
K3	85 (4.6)	0.6 (3.7)	−2.0 (0.4)	34 (26–42)	1.3
K4	101 (5.0)	0.9 (3.3)	−1.6 (0.4)	110 (55–165)	4.4
K5	102 (3.2)	1.9 (4.2)	−2.7 (0.5)	30 (25–35)	1.2
K6	106 (9.4)	1.4 (4.4)	−1.4 (0.3)	78 (28–128)	3.1
J1	102 (6.2)	0.6 (3.8)	−1.4 (0.3)	26 (19–33)	1.0
J2	108 (7.0)	0.2 (3.6)	−1.6 (0.3)	73 (48–98)	2.9
J3	108 (6.0)	0.3 (3.7)	−1.8 (0.3)	50 (40–60)	2.0
J4	107 (5.1)	0.5 (3.8)	−1.8 (0.3)	39 (31–47)	1.5
J5	108 (7.0)	0.7 (3.5)	−1.7 (0.3)	75 (51–99)	3.0
J6	90 (5.9)	0.9 (3.8)	−1.9 (0.4)	48 (37–59)	1.9
J7	98 (9.3)	1.0 (3.6)	−1.5 (0.3)	56 (36–76)	2.2
J8	93 (8.0)	0.1 (3.8)	−1.3 (0.3)	57 (30–84)	2.2
L1	101 (8.7)	0.8 (5.4)	−1.7 (0.4)	41 (26–56)	1.6
L2	106 (6.8)	0.2 (5.3)	−1.4 (0.4)	61 (23–99)	2.4
L3	109 (7.0)	0.6 (4.9)	−1.8 (0.5)	66 (42–90)	2.6
L4	108 (5.8)	0.3 (5.0)	−1.7 (0.5)	76 (40–112)	3.0
L5	96 (7.0)	0.7 (5.1)	−1.4 (0.4)	70 (24–116)	2.8
L6	105 (6.9)	1.1 (5.0)	−2.1 (0.4)	47 (35–59)	1.8
L7	102 (4.3)	2.1 (5.6)	−2.8 (0.7)	30 (25–35)	1.2
L8	102 (3.8)	0.5 (5.4)	−2.7 (0.5)	23 (18–27)	0.9
L9	103 (5.7)	1.3 (5.1)	−2.1 (0.4)	32 (24–40)	1.3
L10	106 (6.0)	0.1 (5.4)	−1.6 (0.4)	48 (29–67)	1.9
L11	97 (8.9)	0.6 (5.4)	−1.2 (0.4)	51 (6–96)	2.0
L12	93 (6.9)	0.4 (5.4)	−1.7 (0.4)	34 (23–45)	1.3
L13	99 (9.8)	0.1 (5.4)	−1.2 (0.4)	22 (12–33)	0.8
L14	101 (5.5)	0.2 (5.4)	−1.8 (0.4)	23 (17–29)	0.9
L15	101 (3.6)	0.5 (5.2)	−1.6 (0.4)	63 (36–90)	2.5
S1	98 (6.4)	0.4 (4.0)	−1.6 (0.4)	74 (42–106)	2.9
S2	77 (8.8)	0.4 (3.9)	−1.9 (0.5)	63 (40–86)	2.5
S3	94 (7.2)	1.5 (4.0)	−1.8 (0.3)	53 (38–68)	2.1
S4	89 (9.2)	0.7 (4.2)	−1.5 (0.3)	46 (26–66)	1.8

(Continues)

TABLE 2 (Continued)

Population	Regression parameters			GR_{50} (95% CI)[a]	SI_{50}[b]
	d (±SE)	c (±SE)	b (±SE)		
S5	88 (6.3)	1.1 (4.1)	−1.8 (0.4)	41 (29–53)	1.6
S6	102 (5.6)	0.2 (4.3)	−1.6 (0.3)	23 (17–29)	0.9
S7	101 (4.8)	0.3 (4.2)	−2.1 (0.4)	37 (29–44)	1.4
S8	106 (3.3)	0.5 (4.6)	−1.1 (0.3)	88 (19–157)	3.5
S9	108 (7.1)	0.5 (5.3)	−1.4 (0.4)	74 (28–120)	2.9
S10	99 (6.3)	0.8 (4.2)	−1.3 (0.3)	51 (24–78)	2.0
S11	92 (3.9)	1.6 (4.0)	−2.7 (0.6)	31 (26–36)	1.2
S12	102 (4.7)	7.3 (5.9)	−4.2 (2.0)	34 (29–39)	1.3
S13	106 (7.0)	1.3 (4.4)	−1.6 (0.3)	40 (30–50)	1.6
S14	103 (4.6)	5.2 (7.2)	−3.3 (1.3)	31 (24–38)	1.2
S15	104 (4.9)	2.4 (6.7)	−2.4 (0.6)	28 (21–35)	1.1
S16	103 (4.6)	4.4 (7.2)	−2.9 (1.0)	30 (23–37)	1.2
H1	99 (5.0)	0.3 (5.6)	−2.2 (0.5)	24 (19–29)	1.0
H2	105 (6.1)	2.0 (6.0)	−1.7 (0.4)	29 (21–37)	1.1
H3	101 (3.8)	0.6 (5.6)	−3.5 (0.9)	26 (22–30)	1.0
H4	99 (4.0)	0.2 (5.6)	−2.9 (0.6)	23 (19–27)	0.9
R1	91 (9.1)	0.4 (5.4)	−1.7 (0.5)	46 (28–64)	1.8
R2	99 (5.0)	0.1 (5.3)	−1.7 (0.5)	59 (32–86)	2.3
R3	100 (4.5)	2.8 (6.0)	−2.8 (0.8)	31 (24–38)	1.2
R4	98 (4.4)	1.6 (5.6)	−3.0 (0.8)	31 (25–37)	1.2
R5	106 (7.2)	0.3 (5.7)	−1.1 (0.3)	25 (12–38)	1.0
R6	96 (3.5)	0.6 (5.6)	−4.6 (1.2)	23 (19–27)	0.9
R7	97 (5.6)	0.3 (5.7)	−1.8 (0.4)	24 (17–31)	1.0
B1	65 (6.3)	0.1 (5.4)	−1.7 (0.7)	51 (21–81)	2.0
B2	86 (5.5)	0.6 (4.7)	−1.5 (0.6)	85 (14–156)	3.4
B3	103 (8.8)	1.3 (5.3)	−1.8 (0.4)	45 (30–60)	1.8
B4	102 (8.5)	1.0 (5.5)	−1.6 (0.4)	33 (21–45)	1.3
B5	101 (9.1)	0.4 (5.7)	−1.2 (0.3)	39 (18–60)	1.5
B6	97 (4.2)	1.9 (4.5)	−4.9 (1.8)	37 (31–43)	1.4
B7	105 (8.1)	0.0 (5.7)	−1.3 (0.4)	30 (15–45)	1.2
B8	98 (7.3)	0.5 (5.2)	−1.5 (0.5)	81 (18–144)	3.2
M1	93 (7.9)	0.3 (6.6)	−1.4 (0.5)	35 (14–56)	1.4
M2	90 (5.6)	1.0 (6.1)	−3.0 (1.0)	32 (24–40)	1.2
M3	89 (6.6)	2.0 (6.3)	−2.3 (0.8)	28 (19–37)	1.1
M4	90 (5.9)	0.4 (6.4)	−2.6 (0.8)	31 (23–39)	1.2
M5	97 (5.4)	2.9 (5.7)	−3.4 (1.1)	38 (30–46)	1.5
M6	101 (5.9)	0.7 (6.7)	−2.3 (0.6)	29 (21–37)	1.1
M7	103 (5.5)	0.8 (6.8)	−2.1 (0.5)	23 (16–30)	0.9
F1	99 (6.9)	2.7 (7.2)	−2.2 (0.8)	35 (25–45)	1.4
F2	101 (6.2)	1.0 (6.5)	−1.5 (0.5)	34 (17–51)	1.3
F3	111 (4.6)	0.4 (6.5)	−1.4 (0.4)	51 (24–78)	2.0
F4	102 (6.2)	0.7 (4.4)	−2.1 (0.4)	47 (37–57)	1.9
F5	77 (3.7)	0.2 (6.6)	−1.6 (0.7)	49 (16–82)	1.9
F6	101 (8.3)	0.8 (6.6)	−1.7 (0.5)	26 (16–36)	1.0

(Continues)

TABLE 2 (Continued)

Population	Regression parameters			GR_{50} (95% CI)[a]	SI_{50}[b]
	d (±SE)	c (±SE)	b (±SE)		
F7	99 (7.4)	1.6 (6.2)	−2.2 (0.6)	37 (26–48)	1.5
F8	93 (8.1)	1.0 (6.7)	−1.7 (0.5)	29 (18–40)	1.1
G1	102 (6.1)	0.4 (5.4)	−1.2 (0.4)	68 (7–129)	2.7
G2	100 (4.9)	0.2 (6.0)	−3.7 (1.3)	31 (26–36)	1.2
G3	102 (6.1)	2.2 (7.1)	−2.1 (0.6)	29 (20–38)	1.1
G4	104 (5.6)	1.7 (7.0)	−2.0 (0.5)	25 (18–32)	1.0
G5	98 (5.3)	0.7 (6.8)	−2.2 (0.6)	23 (17–29)	0.9
SJ	103 (3.7)	1.6 (4.9)	−2.3 (0.4)	26 (19–33)	–
SU	104 (3.9)	1.4 (4.9)	−2.2 (0.4)	25 (18–32)	–

Note: SJ and SU were known susceptible littleseed canary grass populations from Sujana and Uchana, respectively.

Abbreviations: A1–A3, littleseed canary grass populations from Amritsar district; B1–B8, populations from Barnala district; F1–F8, populations from Ferozepur district; G1–G5, populations from Gurdaspur district; H1–H4, populations from Hoshiarpur district; J1–J8, populations from Jalandhar district; K1–K6, populations from Kapurthala district; L1–L15, populations from Ludhiana district; M1–M7, populations from Moga district; P1–P2, populations from Patiala district; R1–R7, populations from Ropar district; S1–S16, populations from Sangrur district; T1–T4, populations from Tarantaran district; FS1–FS2, populations from Fatehgarh sahib district; CI, confidence interval; SI, sensitivity index.

[a]GR_{50} are effective doses (g a.i. ha^{-1}) of CP required for 50% reduction in shoot dry weight of each tested population.

[b]SI is calculated as a ratio of GR_{50} of each tested littleseed canary grass population to averaged GR_{50} values of the SJ and SU populations.

crop rotations (other than rice-wheat rotation) had fewer problems of littleseed canary grass with reduced sensitivity to CP (Kaur & Kaur, 2018). Less than 40% control of littleseed canary grass has previously been reported in wheat with field-use rate of CP, fenoxaprop-*p*-ethyl, and pinoxaden herbicides (Navjyot-Kaur et al., 2016). Previous research has also shown that alternative herbicides, including sulfosulfuron and pinoxaden, can provide effective control of CP-resistant littleseed canary grass populations in wheat (Das et al., 2013). Therefore, producers in Punjab should adopt diversified crop rotations along with rotational use of alternative effective herbicides (sulfosulfuron or pinoxaden) for managing CP-resistant littleseed canary grass as well as for further delaying CP resistance development.

3.2 | Sensitivity to isoproturon

In general, all tested littleseed canary grass populations exhibited high sensitivity to IPU than the CP herbicide (Table 3). Results from dose-response studies indicated that both susceptible populations (SJ and SU) were effectively controlled with IPU (only 422 and 417 g a.i. ha^{-1} of IPU for a 50% reduction in shoot dry weights although the recommended field-use rate of IPU is 938 g a.i. ha^{-1}). Furthermore, the highest tested rate (3750 g a.i. ha^{-1}, four times the recommended field-use rate of 938 g a.i. ha^{-1}) of IPU herbicide resulted in complete mortality and maximum shoot dry weight reduction of all tested populations. Based on GR_{50} values, the SI range was estimated to be <1.5 among the majority of the tested populations from Patiala, Fatehgarh Sahib, Kapurthala, Jalandhar, Ludhiana, Sangrur, Hoshiarpur, Barnala, Moga, Ferozepur, and Gurdaspur districts, indicating high sensitivity to IPU herbicide (Table 3). The SI range of >1.5 was only estimated in two littleseed canary grass populations: one from Tarantaran (T2) and another from Amritsar (A2) (Table 3). The IPU-resistant littleseed canary grass has previously been reported in Haryana, Punjab, Uttar Pradesh, and Delhi (Chhokar & Malik, 2002; Chhokar & Sharma, 2008; S. Singh, 2007). However, the level of IPU resistance differed among various littleseed canary grass populations (2.6- to 13.7-fold SI) as reported by Chhokar and Malik (2002), Bhullar et al. (2017), and Malik and Singh (1995). Results from the current research indicated that the SI range for IPU herbicide was very low (none of the tested populations exhibited >1.7-fold SI), and all tested populations from Punjab were found to be relatively sensitive. The IPU herbicide has not been used by wheat producers in the region for more than 15 years primarily due to herbicide resistance. Results from the current research revealed that the same littleseed canary grass populations with a relatively high SI range (>3.5) for CP had a low SI range (<1.5-fold SI) for IPU herbicide.

4 | CONCLUSIONS AND IMPLICATIONS

This study reported the sensitivity of littleseed canary grass populations (94 total) collected from wheat fields during 2018 and 2019 from Punjab, India, to CP and IPU herbicide. Although littleseed canary grass resistant to CP and IPU has previously been reported in Punjab, the current study provided baseline data on the sensitivity response of littleseed

TABLE 3 Regression parameters (using Equation 1) for whole plant dose-response assays (at 21 days after treatment) on the basis of percent shoot dry weight reduction of littleseed canary grass populations from Punjab, India, treated with various rates of isoproturon (0, 234.5, 469, 938, 1876, and 3752 g a.i. ha^{-1}) during 2018 and 2019.

	Regression parameters				
Population	**d (±SE)**	**c (±SE)**	**b (±SE)**	**GR_{50} (95% CI)[a]**	**SI[b]**
T1	101 (5.3)	0.0 (6.0)	−2.1 (0.5)	387 (286–488)	0.9
T2	103 (8.5)	0.9 (5.9)	−1.9 (0.5)	715 (481–949)	1.7
T3	102 (4.5)	6.1 (6.8)	−3.7 (1.7)	500 (405–596)	1.2
T4	98 (4.2)	5.2 (5.6)	−4.4 (2.1)	500 (427–574)	1.2
A1	105 (7.2)	0.2 (6.0)	−1.7 (0.4)	442 (295–589)	1.1
A2	110 (9.8)	0.2 (5.9)	−1.6 (0.4)	671 (410–932)	1.6
A3	103 (5.4)	1.0 (6.1)	−2.0 (0.5)	404 (295–514)	1.0
P1	104 (6.3)	0.6 (6.1)	−1.7 (0.4)	406 (280–531)	1.0
P2	101 (4.4)	0.5 (6.0)	−2.6 (0.6)	360 (279–441)	0.9
FS1	101 (6.7)	0.3 (5.8)	−1.3 (0.3)	536 (272–801)	1.3
FS2	106 (7.3)	0.1 (5.7)	−1.8 (0.4)	591 (414–769)	1.4
K1	102 (4.2)	0.9 (5.9)	−2.6 (0.5)	371 (292–449)	0.9
K2	103 (4.6)	1.2 (6.0)	−2.3 (0.5)	401 (308–494)	1.0
K3	102 (4.9)	0.8 (5.8)	−2.3 (0.5)	434 (335–534)	1.0
K4	100 (4.2)	5.6 (4.3)	−5.8 (2.3)	567 (468–665)	1.4
K5	103 (4.4)	1.4 (6.0)	−2.4 (0.5)	397 (309–486)	1.0
K6	102 (5.4)	0.2 (5.8)	−1.8 (0.5)	323 (235–412)	0.8
J1	104 (6.6)	0.7 (5.6)	−2.0 (0.4)	557 (402–711)	1.3
J2	102 (4.3)	0.6 (5.9)	−2.4 (0.5)	344 (268–420)	0.8
J3	103 (4.7)	0.9 (5.9)	−2.1 (0.4)	351 (265–438)	0.8
J4	102 (4.1)	1.1 (5.9)	−2.7 (0.6)	387 (307–467)	0.9
J5	103 (4.3)	0.8 (5.9)	−2.4 (0.5)	359 (278–439)	0.9
J6	104 (6.7)	0.0 (5.8)	−1.7 (0.4)	445 (310–580)	1.1
J7	103 (5.6)	0.3 (5.8)	−2.0 (0.5)	440 (326–554)	1.1
J8	106 (6.9)	1.1 (5.9)	−1.8 (0.4)	523 (369–678)	1.3
L1	101 (4.9)	0.2 (6.8)	−2.5 (0.7)	308 (232–385)	0.7
L2	103 (5.2)	1.2 (7.0)	−2.3 (0.6)	378 (276–480)	0.9
L3	107 (9.2)	0.9 (6.9)	−1.7 (0.5)	551 (341–762)	1.3
L4	106 (8.8)	0.6 (6.9)	−1.6 (0.4)	500 (310–691)	1.2
L5	100 (9.8)	0.1 (6.8)	−1.6 (0.5)	503 (289–717)	1.2
L6	103 (5.0)	1.1 (7.0)	−2.5 (0.6)	376 (280–473)	0.9
L7	102 (4.9)	1.4 (7.0)	−2.7 (0.7)	400 (302–498)	1.0
L8	102 (4.9)	1.0 (7.0)	−2.6 (0.6)	382 (287–478)	0.9
L9	103 (5.1)	1.0 (7.0)	−2.4 (0.6)	372 (274–469)	0.9
L10	102 (5.7)	8.0 (9.0)	−3.5 (2.2)	528 (398–658)	1.3
L11	102 (6.4)	0.3 (6.8)	−2.1 (0.6)	452 (320–584)	1.1
L12	102 (5.7)	0.6 (6.9)	−2.3 (0.6)	408 (297–520)	1.0
L13	102 (5.0)	2.5 (7.2)	−2.8 (0.8)	446 (337–555)	1.1
L14	103 (6.0)	6.8 (5.2)	−2.8 (1.7)	510 (329–692)	1.2
L15	103 (5.0)	2.2 (7.2)	−2.7 (0.7)	429 (321–536)	1.0
S1	102 (5.2)	0.6 (6.4)	−2.3 (0.6)	405 (303–508)	1.0
S2	103 (4.9)	3.3 (7.0)	−2.6 (0.7)	455 (341–570)	1.1
S3	103 (5.3)	1.2 (6.5)	−2.1 (0.5)	388 (282–494)	0.9

(Continues)

TABLE 3 (Continued)

Population	Regression parameters			GR_{50} (95% CI)[a]	SI[b]
	d (±SE)	c (±SE)	b (±SE)		
S4	107 (8.5)	0.6 (6.4)	−1.6 (0.4)	487 (306–668)	1.2
S5	103 (6.0)	1.0 (6.4)	−2.2 (0.6)	495 (364–626)	1.2
S6	101 (5.3)	0.2 (6.3)	−2.3 (0.6)	414 (311–517)	1.0
S7	108 (9.9)	0.5 (6.4)	−1.4 (0.4)	475 (271–679)	1.1
S8	103 (6.7)	0.2 (6.3)	−2.0 (0.5)	472 (331–614)	1.1
S9	103 (5.8)	1.8 (6.5)	−2.3 (0.6)	499 (369–628)	1.2
S10	102 (5.3)	0.6 (6.4)	−2.3 (0.6)	407 (305–510)	1.0
S11	102 (5.1)	6.4 (7.2)	−3.4 (1.5)	524 (414–634)	1.3
S12	103 (4.8)	0.7 (6.5)	−2.3 (0.5)	350 (262–438)	0.8
S13	102 (4.7)	5.9 (7.4)	−3.6 (1.7)	495 (394–596)	1.2
S14	102 (4.9)	0.5 (6.4)	−2.2 (0.5)	320 (238–402)	0.8
S15	103 (4.9)	1.0 (6.5)	−2.2 (0.5)	362 (269–456)	0.9
S16	103 (4.9)	2.1 (6.7)	−2.4 (0.6)	416 (311–521)	1.0
H1	103 (7.2)	0.3 (7.1)	−1.9 (0.5)	414 (275–553)	1.0
H2	102 (5.1)	0.8 (7.2)	−2.6 (0.7)	369 (276–464)	0.9
H3	103 (5.7)	0.7 (7.2)	−2.1 (0.6)	347 (245–450)	0.8
H4	103 (5.5)	2.6 (7.6)	−2.5 (0.7)	435 (314–557)	1.0
R1	103 (5.5)	1.2 (7.3)	−2.4 (0.6)	390 (282–499)	0.9
R2	105 (8.2)	0.4 (7.0)	−1.9 (0.5)	533 (347–719)	1.3
R3	103 (5.5)	0.7 (7.2)	−2.2 (0.6)	351 (251–451)	0.8
R4	103 (5.5)	1.8 (7.4)	−2.5 (0.7)	431 (315–546)	1.0
R5	102 (5.4)	6.5 (8.7)	−3.5 (1.9)	505 (383–627)	1.2
R6	103 (5.3)	3.3 (7.8)	−2.8 (0.9)	454 (335–574)	1.1
R7	103 (5.5)	3.5 (7.9)	−2.6 (0.8)	457 (328–586)	1.1
B1	107 (9.3)	1.3 (7.1)	−1.8 (0.5)	639 (410–869)	1.5
B2	103 (7.6)	0.2 (7.1)	−1.8 (0.5)	416 (271–562)	1.0
B3	105 (8.0)	0.9 (7.2)	−1.8 (0.5)	500 (326–674)	1.2
B4	104 (5.6)	1.7 (7.4)	−2.2 (0.6)	399 (283–515)	1.0
B5	103 (5.4)	3.4 (7.8)	−2.7 (0.9)	464 (340–587)	1.1
B6	102 (5.3)	3.9 (7.8)	−3.0 (1.1)	480 (360–600)	1.1
B7	103 (6.1)	2.2 (7.5)	−2.2 (0.6)	457 (323–591)	1.1
B8	103 (5.8)	1.6 (7.4)	−2.2 (0.6)	414 (294–533)	1.0
M1	105 (8.2)	1.2 (7.4)	−1.8 (0.5)	479 (306–653)	1.1
M2	104 (6.8)	3.4 (8.0)	−2.2 (0.7)	502 (345–660)	1.2
M3	101 (5.6)	3.4 (6.2)	−3.7 (1.3)	562 (448–675)	1.3
M4	102 (5.7)	1.2 (7.3)	−2.5 (0.7)	424 (309–539)	1.0
M5	103 (7.1)	0.4 (7.2)	−2.0 (0.6)	439 (297–582)	1.1
M6	103 (7.2)	0.1 (7.1)	−2.0 (0.6)	447 (302–591)	1.1
M7	103 (5.4)	4.1 (8.3)	−2.9 (1.1)	467 (340–594)	1.1
F1	105 (8.5)	0.8 (7.3)	−1.7 (0.5)	472 (295–650)	1.1
F2	104 (7.8)	1.7 (7.2)	−2.1 (0.6)	586 (401–771)	1.4
F3	104 (8.2)	0.2 (7.2)	−1.8 (0.5)	454 (287–622)	1.1
F4	104 (6.8)	2.4 (7.7)	−2.1 (0.6)	482 (332–633)	1.2
F5	102 (5.9)	3.6 (7.8)	−2.7 (1.0)	501 (369–633)	1.2
F6	103 (5.9)	4.5 (8.7)	−2.6 (1.0)	492 (346–638)	1.2

(Continues)

TABLE 3 (Continued)

Population	Regression parameters			GR_{50} (95% CI)[a]	SI[b]
	d (±SE)	c (±SE)	b (±SE)		
F7	103 (5.5)	2.2 (7.6)	−2.5 (0.7)	420 (302–537)	1.0
F8	103 (6.3)	1.3 (7.4)	−2.1 (0.6)	413 (286–541)	1.0
G1	104 (6.7)	2.4 (7.7)	−2.1 (0.6)	471 (324–618)	1.1
G2	102 (5.6)	3.4 (7.4)	−3.1 (1.1)	503 (384–621)	1.2
G3	103 (5.8)	1.7 (7.5)	−2.3 (0.6)	407 (288–526)	1.0
G4	103 (5.4)	2.1 (7.6)	−2.6 (0.7)	419 (305–533)	1.0
G5	102 (5.5)	2.3 (7.5)	−2.7 (0.8)	451 (335–568)	1.1
SJ	103 (5.5)	2.4 (7.7)	−2.4 (0.7)	422 (303–542)	–
SU	103 (5.3)	2.1 (7.6)	−2.6 (0.7)	417 (305–530)	–

Note: SJ and SU were known susceptible littleseed canary grass populations from Sujana and Uchana, respectively.

Abbreviations: A1–A3, littleseed canary grass populations from Amritsar district; B1–B8, populations from Barnala district; F1–F8, populations from Ferozepur district; G1–G5, populations from Gurdaspur district; H1–H4, populations from Hoshiarpur district; J1–J8, populations from Jalandhar district; K1–K6, populations from Kapurthala district; L1–L15, populations from Ludhiana district; M1–M7, populations from Moga district; P1–P2, populations from Patiala district; R1–R7, populations from Ropar district; S1–S16, populations from Sangrur district; T1–T4, populations from Tarantaran district; FS1–FS2, populations from Fatehgarh sahib district; CI, confidence interval; SI, sensitivity index.

[a]GR_{50} are effective doses (g a.i. ha^{-1}) of isoproturon required for 50% reduction in shoot dry weight of each tested population.

[b]SI is calculated as a ratio of GR_{50} of each tested littleseed canary grass population to averaged GR_{50} values of the SJ and SU populations.

canary grass populations collected from a wide geographical area in Punjab (compared to previous studies). This information will help understand future population shifts in the region as influenced by the adoption of various agronomic practices and changing climatic conditions. Reduced sensitivity (putative resistance) to CP observed in some littleseed canary grass populations will pose a serious management challenge for wheat producers. To delay the spread of less sensitive biotypes, land managers should frequently scout wheat fields after CP applications for littleseed canary grass escapes and eliminate those survivors prior to seed set. Our results clearly indicated the need for the adoption of integrated and more diversified weed management strategies in order to tackle the increasing problem of reduced sensitivity to CP among littleseed canary grass populations. It is important that wheat producers quickly implement best management practices including the adoption of wheat sowing in rice straw residue with Happy Seeder drills (tractor-mounted drill that cuts and lifts rice straw, sows wheat, and deposits the rice straw uniformly over the wheat sown areas in a single pass), use of no-till drills, altering row spacing, timing and method of fertilizer application, and utilizing harvest weed seed control strategies or any other weed control tactics that would reduce the soil seed bank of littleseed canary grass populations.

Future studies will continue monitoring the sensitivity of littleseed canary grass populations from Punjab, India, to other commonly used herbicides in wheat. Single point mutations ($Trp_{2027}Cys$ and $Asp_{2078}Gly$) conferring resistance to ACCase inhibitors have previously been reported in littleseed canary grass populations from Iran (Gherekhloo et al., 2012). The underlying mechanism(s) of reduced sensitivity to CP in selected littleseed canary grass populations from Punjab, India, is currently unknown and will also be investigated.

AUTHOR CONTRIBUTIONS

Gurpreet Kaur: Conceptualization; data curation; formal analysis; investigation; writing—original draft. **Tarundeep Kaur**: Conceptualization; funding acquisition; methodology; project administration; resources; supervision; writing—review and editing. **Makhan Singh**: Conceptualization; project administration; resources; supervision; writing—review and editing. **Priyanka Sharma**: Software; visualization; writing—review and editing. **Vipan Kumar**: Data curation; methodology; validation; visualization; writing—review and editing.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

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