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Effect of cushioned or single layer semen centrifugation before sex sorting on frozen stallion semen quality

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1 EFFECT OF CUSHIONED OR SINGLE LAYER SEMEN CENTRIFUGATION BEFORE SEX SORTING ON
2 FROZEN STALLION SEMEN QUALITY

3

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21 **ABSTRACT**

22 The aim of this study was compare the effect of pre-sorting centrifugation (cushioned (CC), or single-
23 layer colloid (SLC)), to simple dilution (SD), on the quality of sex-sorted stallion semen before and
24 after sorting and after freezing and thawing. Four ejaculates from each of two fertile stallions were
25 collected one week apart and evaluated for percent total sperm motility (TM), percent viable-
26 acrosome intact sperm (VAI) and DNA quality (% DFI). Freezing caused, independently from CC and
27 SLC treatments, a significant decrease of TM ($p<0.05$) and VAI ($p<0.05$) in both unsorted and sorted
28 semen. On the other hand, sorting did not impair TM and VAI and, interestingly, improved DNA
29 quality in all treatments only before freezing (28 vs 13, 28 vs 10, 22 vs 7 in SD, CC and SLC for
30 unsorted vs sorted groups respectively; $p<0.05$); this positive effect was lost in the same samples
31 after freezing and thawing, suggesting that the freezing process reduces the DNA quality of sex-
32 sorted sperm. Our results suggest that CC and SLC are not able to select those spermatozoa that
33 possess a better ability to withstand sperm processing associated with sperm sorting and freezing.

34

35 **Keywords**

36 Sexed semen, horse, cushioned centrifugation, single-layer colloid centrifugation

37

38 **1. Introduction**

39

40 Depending on the species, there are different reasons for performing gender selection prior to
41 insemination primarily due to economic advantages of a particular sex. In horses, sex selection may
42 also have an economic advantage such as the production of fillies in the Polo industry, or it may be
43 rather subjective and due to a preference for the sex of a particular pedigree (1).

44 Commercial application of this process has been limited mainly by two factors: close proximity of
45 the mare to the semen processing laboratory (2,3,4) and, more important, the poor quality of
46 frozen-thawed sex-sorted stallion spermatozoa (1,2).

47 The development of procedures to cool and freeze sex-sorted sperm will be critical if this technology
48 is to be embraced by the equine industry worldwide (1).

49 Pregnancy rates obtained with frozen-thawed sex-sorted stallion semen ranged between 0% and
50 16% when inseminating between 5 and 20x10⁶ by hysteroscopic or rectally-guided insemination
51 (5,6). Recently Gibb et al. were able to achieve pregnancy rate of 27% after insemination with frozen
52 sex-sorted sperm, but there was a high incidence of early embryonic death (7).

53 Moreover, when used by ICSI for *in vitro* embryo production, the fertilizing ability of sex-sorted
54 frozen-thawed spermatozoa is lower (range-20- 30%), compared to non-sorted frozen-thawed
55 sperm (range-71-83%) (8,9), even if the capability of establishing normal pregnancies is the same as
56 non-sorted frozen-thawed semen (8).

57 Centrifugation of equine semen is commonly used to maximize sperm quality for semen
58 preservation both cooled and frozen (10). Cushioned and colloid centrifugation, in particular single-
59 layer colloid centrifugation, are techniques extensively used for reducing sperm damage and for
60 selecting high quality sperm respectively (10-15).

61 The aim of this study was to investigate the effect of different pre-sorting treatments such as
62 cushioned and single-layer colloid centrifugation, on the quality of sex-sorted stallion sperm before
63 and after freezing and thawing.

64

65 **2. Materials and methods**

66 The experiment was approved by the Ethic-scientific Committee of Alma Mater Studiorum,
67 University of Bologna.

68 Unless otherwise stated, all chemicals were purchased from Sigma-Aldrich (Milan, Italy).

69

70 **2.1. Semen collection and pre-sorting treatments**

71 Four ejaculates from two fertile stallions, one Trotter and one Connemara pony 15 and 18 years old
72 respectively, were collected one week apart by a Missouri model artificial vagina, equipped with a
73 disposable liner and an online filter, after one week of a once a day collection for depleting
74 extragonadal reserves. Sperm concentration was evaluated in the gel-free semen volume using a
75 fluorescence-based instrument (NucleoCounter SP-100; Chemometec, A/S, Allerød, Denmark) (13).
76 Each ejaculate was diluted in KMT extender (16) to a concentration of 100×10^6 sperm/mL and
77 divided into three different treatments: simple dilution (SD), cushioned centrifugation (CC) and
78 single-layer colloid centrifugation (SLC).

79 For CC, 39mL of extended semen were first loaded in a 50mL glass conical tube, then 1mL of a
80 cushion solution (Cushion Fluid, Minitube, Germany) was layered beneath the extended semen
81 using a blunt-tipped 3.5-inch 18 ga spinal needle attached to a 20-mL sterile syringe.

82 For SLC, a 70% gradient solution was prepared using a silica particle solution (RediGrad, GE
83 Healthcare Life, Sciences) diluted with a calcium-free buffer, and pH and osmolarity were adjusted
84 to about 7.0 and about 300 mOsm/L respectively; 20mL extended semen were gently layered onto

85 20mL of the gradient solution in a 50mL glass conical tube. CC and SLC semen samples were then
86 centrifuged simultaneously at 300 x g for 20' (Thermo IEC CL 10 Centrifuge). After centrifugation, in
87 the CC sample the supernatant was aspirated, most of the cushion solution was removed by
88 aspiration and the remaining 5mL sperm pellet was resuspended in KMT extender to 100×10^6
89 sperm/ML. In the SLC sample, supernatant and most of the gradient were discharged, the sperm
90 pellet aspirated through a 100 mL pipette and resuspended in KMT extender to 100×10^6 sperm/ML.

91

92 **2.2.** *Flow cytometric sperm-sorting and freezing procedure*

93 Aliquots of 1mL of semen of each treatment (100×10^6 sperm/mL) were incubated with 10 μ l of
94 Hoechst 33342 (5 mg/mL) 0.09-mM final concentration for 1h and 30 min at 35°C in the dark. Just
95 prior to sorting, 1 μ l of food dye (FD&C#40, Warner Jenkinson, St. Louis, MO, USA) stock solution
96 (25 mg/mL) was added to each sample to identify membrane damaged spermatozoa by quenching
97 the Hoechst 33342 fluorescence. The samples were then filtered through a 60 μ m nylon mesh filter
98 to remove debris or clumped spermatozoa. A MoFlo SX[®] flow cytometer (DakoCytomation Inc., Fort
99 Collins, CO, USA) equipped with an argon laser (wavelength 351 nm at 150 mW) was used. All live
100 cells were sorted since separation of X from Y-bearing spermatozoa was not an aim of the work.
101 Sorted spermatozoa were collected in polypropylene tubes containing 500 μ l of 2.5% TEST-egg yolk
102 buffer (17). After collection of 8×10^6 spermatozoa per tube, the samples were centrifuged at 800
103 X g for 20 min and resuspended in Heitland extender (18) with 3% egg yolk and 3% glycerol, packed
104 in 0,25mL straws and frozen in a floating styrofoam box system 6 cm under liquid nitrogen vapour
105 for 20'. Samples were thawed in water bath at 35°-37°C for 30'' and immediately analyzed.

106

107 **2.3.** *CASA*

108 Motility evaluation was performed using a computer assisted sperm analyzer (Hamilton Thorn IVOS
109 Vers 12.2L); semen was extended to 30×10^6 sperm/ML and thousand cells were analyzed using a
110 fixed height Leja Chamber SC 20-01-04-B, Netherland. CASA settings from standard equine set-up
111 were: frames x sec 60 Hz, N° of frames 45, Minimum contrast 70, Minimum Cell Size 4 pixel, Cell Size
112 6 pixel, Cell Intensity 106, Pat Velocity (VAP) 50 μ m/sec, Straightness (%) 70%, VAP cut off 20 μ m/sec.

113

114 **2.4.** *Viability and acrosome integrity*

115 Sperm acrosome intactness assay (fluoresceinated *Pisum sativum*-PSA/propidium iodide-PI) was
116 used for evaluating viability and acrosome integrity by flow-cytometry (19). Viable, plasma
117 membrane intact sperm (VAI) were those cells that did not acquire the PI, while non-viable sperm
118 were those that fluoresce red due to PI uptake. Fifty microliters from each treatment were diluted
119 with 133µl of Dulbecco phosphate buffer saline solution (D-PBS, Invitrogen Gibco,® Carlsbad, CA,
120 USA) and stained with 2µl of PI (Invitrogen Molecular Probes, Eugene, OR, USA; 2.4 mM working
121 solution) and 0.05 mg/mL PSA . Samples were incubated at room temperature in the dark for 10
122 min, and then 20µl of the stained sample were mixed with 400µl of D-PBS and subjected to analysis.
123 A flow rate of approximately 300 events/sec was used and a total of 5000 events were evaluated
124 per sample. List-mode data were analyzed by WinList™ software (Verity Software House, Topsham,
125 ME, USA).

126

127 **2.5.** *Sperm Chromatin Structure Assay (SCSA)*

128 Sample preparation and processing, as well as flow cytometer adjustments, were performed as
129 previously described (20). Briefly, an aliquot of each semen samples was immediately frozen and
130 stored in a -20°C freezer until analysis (max two weeks). The sperm samples were handled
131 individually and were thawed in a 35 to 37°C water bath. Immediately following thawing (30 to 60
132 sec), a 2-7uL aliquot o f semen was diluted to 200 uL in a buffer solution (0. 186g disodium EDTA,
133 0.790 g Tris-HCl, 4.380 g NaCl in 500 mL deionized water,pH7.4). This was mixed with 400 uL of acid-
134 detergent solution(2.19gNaC~ 1.0 mL of2N HCl solution, 0.25 mL Triton-X, qs. 250 mL deionized
135 water). After 30 sec, 1.2 mL of the acridine orange (AO) solution was added (3.8869 g citric acid
136 monohydrate, 8.9429 g NazH}IO... 4.3850 g NaO, 0.1700 g disodium EDTA, 4 ug/mL acridine orange
137 stock solution (1mg/mL),qs.500mLwater,pH6.0). The sample was covered with aluminum foil and
138 placed in the flow cytometer, and allowed to pass through the tubing for 2 min prior to counting
139 of the cells. The cell flow rate was placed on the high setting for the machine, which, based on sperm
140 concentration in the solution, resulted in an actual flow rate of 100-200cells/sec. A total of 5000

141 events was evaluated for each sample. Sperm from a control stallion were used as a biologic control
142 to standardize instrument settings between days of use. The flowcytometer was adjusted such that
143 the mean green fluorescence was set at 500 channels (FI-I @ 500) and mean red fluorescence at
144 150 channels (FI-3@150).. Data were acquired in a list-mode and analysis was performed using
145 WinList™ software (Verity Software House, Topsham, ME, USA). The percent of sperm with
146 abnormal DNA was defined by the parameter DNA fragmentation index (DFI).

147

148 **2.6.** *Experimental design*

149 Spermatozoa were evaluated for motility, viable-acrosome intactness and chromatin integrity
150 before (SD) and after the different treatments (CC, SLC); analysis were repeated after sorting
151 aliquots of semen from the different treatments, and after freezing and thawing both sorted and
152 unsorted semen.

153

154 **2.7.** *Statistical analysis*

155 The normal distribution of the data was checked using the Lillefors test. In light of the normal
156 distribution, the data were analyzed using an ANOVA model. When significant differences were
157 found Tukey post-hoc test was performed to assess the difference between: D, CC and SLC
158 treatments; unsorted and sorted samples; pre- and post-freezing. The level of significance was set
159 at $P < 0.05$. All analyses were performed using R version 3.0.3. (Copyright © 2014, The R Foundation
160 for Statistical Computing).

161

162 **3. Results**

163 *3.1. Motility evaluation*

164 Percent total sperm motility (TM) was similar among pre-sorting treatments (D, CC, SLC) that were
165 sorted and frozen ($P>0.05$). Freezing induced a significant decrease in TM compared to unfrozen
166 samples ($P<0.05$) while TM was similar in unsorted and sorted samples ($P>0.05$) (Tab. 1).

167

168 *3.2. Viability and acrosome integrity*

169 Percent of viable-acrosome intact (VAI) spermatozoa was similar among pre-sorting treatments that
170 were sorted and frozen ($P>0.05$). Percent VAI was less in frozen-thawed than unfrozen samples
171 ($P<0.05$), while no effect of sorting was recorded both in unfrozen and frozen samples ($P>0.05$)
172 (Tab. 1).

173

174 *3.3. Sperm Chromatin Structure Assay (SCSA)*

175 The results on DNA quality are summarized in Table 1.

176 Pre-freeze sorted samples had lower % DFI than pre-freeze unsorted samples ($p<0.05$); however,
177 the % DFI post-thaw among pre-sorting treatments in unsorted, sorted and sorted frozen groups
178 did not differ.

179 SLC showed a significantly lower % DFI ($P<0.05$) compared to D in unsorted frozen samples.

180

181 **4. Discussion**

182 The aim of this study was to investigate the effect of different pre-sorting treatments, cushioned
183 centrifugation and single-layer colloid centrifugation compared to simple dilution, on sorted stallion
184 sperm quality before and after freezing.

185 Cushioned centrifugation and colloid single-layer centrifugation were chosen as treatments,
186 compared to simple dilution, because, as reported before, these procedures are becoming a
187 commonplace in processing stallion semen (10). Other procedures have been reported for

188 concentrating sperm (20) or for selecting high quality sperm (15), but centrifugation, with or without
189 cushion, and colloid centrifugation, particularly using a single-layer, have been the most used in
190 processing stallion semen for cooling and freezing.

191 Samples obtained after these treatments differ from the untreated samples being a selected
192 population of sperm obtained with colloid centrifugation, and reduction of the amount of seminal
193 plasma after cushioned centrifugation.

194 Centrifugation of stallion semen can be harmful, especially when spermatozoa are packed tightly at
195 the bottom of the tubes after vigorous centrifugation, so different solutions layered at the bottom
196 of the tubes has been used to provide a “cushion” for spermatozoa during centrifugation (21).

197 Cushioned centrifugation can be used to provide a high sperm harvest while maintaining sperm
198 function, and the volume of “cushion” solution can be reduced to 1mL in conical bottom-tubes
199 without impairing sperm harvest or semen quality (10). Recently Len et al. (22) compared sperm
200 recovery rate, sperm motility (total and progressive), sperm plasma membrane integrity, and
201 acrosomal integrity after cushioned or noncushioned centrifugation of equine semen extended in a
202 commercial semen extender and subjected to higher centrifugal forces (900 and 1800 x g) than that
203 commonly recommended (400–600 g) for noncushioned centrifugation and lower centrifugation
204 time (10 min) than commonly used for cushioned centrifugation (20 minutes), and they found
205 optimal recovery rate and sperm quality after 900 x g non cushioned centrifugation. The aim of the
206 present study was not to optimize sperm recovery rate but to centrifuge semen trying to avoid
207 sperm damage, and this is the reason why cushioned centrifugation was performed with low
208 centrifugation force (300 x g). Processing sperm in this way did not modify the quality of fresh semen
209 in terms of motility, viability-acrosome integrity and DNA integrity, in agreement with Edmond et
210 al. (23).

211 It has been reported that SLC selects sperm with higher progressive motility and better morphology,

212 increases the shelf life of stored semen and improves survival and fertility of frozen semen (15).
213 However, in our study we did not find any increase in the percentage of total motility and viable
214 acrosome intact sperm following SLC treatment in unsorted and sorted semen, either pre and post-
215 freezing,.

216 CC and SLC , followed by resuspension of sperm pellet, have as consequence the partial and total
217 removal of seminal plasma respectively (SP) (15,21). SP has been shown to be detrimental to stallion
218 spermatozoa during storage, and sperm motility, viability, membrane integrity and fertility are
219 better maintained when SP is diluted to 25% or less of its original volume, and this can be
220 accomplished through centrifugation (21,24).

221 During SLC, SP is retained on the top of the colloid, removing some components that are beneficial
222 to fertilization such as cysteine-rich secretory proteins (CRISP) and non-protein constituents, such
223 as cholesterol, that may protect the spermatozoa during *in vitro* storage (15).

224 Flow cytometric sex-sorting of sperm is time-consuming because sperm must pass individually
225 through the laser beam. In this study the interval between semen collection and sorting procedure
226 of all different treatments was between 2 to 4 hours, during which the semen was held at room
227 temperature, but differences in the amount of SP between samples (50%, ~20% and ~0% in
228 treatments D, CC and SLC respectively) did not affect the sperm quality after sorting.

229 Our results suggest that processing stallion sperm by either CC or SLC does not improve the quality
230 (i.e. sperm motility, viability-acrosome integrity and DNA integrity) of fresh semen. In addition, pre-
231 sorting treatment did not improve the quality of post-thaw sperm compared to simple dilution.
232 Similar to a previous study (25), these results suggest that CC and SLC cannot select a sperm
233 population that are more resistant to the sorting and freezing procedure.

234 The only significant positive effect of pre-sorting treatments was observed in unsorted frozen semen
235 in which the percentage of spermatozoa bearing damaged DNA was significantly reduced in SLC
236 treated sperm. This data agree with the results of Hoogewis et al (26), who reported a significant
237 positive effect of SLC on DFI after freezing and thawing; in that study, however, a different colloid
238 solution was used.

239 Our results indicate that the freezing procedure induces, independently from CC and SLC
240 treatments, the most serious damage in term of total motility and viability, causing a significant
241 decrease of these parameters in both unsorted and sorted semen. On the other hand, the sorting
242 procedure does not impair sperm quality relatively to these parameters in agreement with previous
243 observations (27,28).

244 The sorting procedure improved DNA quality, as assayed by SCSA, in all groups (D, CC and SLC) prior
245 to freezing. Bochenek et al. (29) reported no detrimental effects of sex sorting on sperm chromatin,
246 whereas the positive effect of sorting on the DNA integrity of the sperm cell population was
247 described in bull (30,31); all these observations agree with the fertility results reported with fresh
248 sex-sorted semen (1-4).

249 In both bull and stallion spermatozoa almost all the DNA is packaged by protamine and this could
250 be one of the reasons for the relative insensitivity to sorting damage of the chromatin in these
251 species compared with human spermatozoa (32,33). However, not only did we find an absence of
252 DNA damage but also an increase in the percentage of DNA intact sperm after sorting. An
253 explanation could be found in the effectiveness of the discarding system of membrane damaged
254 cells by gating out those spermatozoa that present Hoechst33342 fluorescence quenched by
255 FD&C#40. A correlation between sperm viability and DNA integrity was demonstrated in bulls by
256 Gosalvez et al. (31) who observed that a large proportion of DNA damaged spermatozoa are
257 accumulated in the wasted population due to the simultaneous presence of membrane injury.

258 The positive effect of the sorting procedure on DNA integrity was lost after freezing and thawing
259 suggesting that the freezing process reduces the DNA quality of sex-sorted sperm. This could explain
260 the low viability of embryos and the high rate of embryonic death observed with the use of
261 cryopreserved sex-sorted semen (7), and also the lower level of fertilizing ability compared to non-
262 sorted frozen semen reported by Colleoni et al (8), when sex-sorted frozen sperm were used by ICSI
263 for *in vitro* embryo production.

264 Cryoprotectants different from glycerol, as dimethyl formamide (25) and antioxidants (34) have been
265 shown to ameliorate the quality of semen and the effects of oxidative stress during the
266 cryopreservation of sex- sorted equine sperm, so further studies are needed to optimize extender
267 quality to reduce sperm damage during sorting and freezing procedures.

268

269

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273 **Conflict of interest**

274 The authors declare that no competing interests exist

275

276

277

278 **REFERENCES**

279

- 280 1. Samper JC, Morris LH, Pena FJ, Plough TA. Commercial breeding with sexed stallion semen :
281 reality or fiction? J Eq Vet Sc 2012;32:471-474
- 282 2. Samper JC Update on the status of stallion sexed semen, 2014, Proceeding of annual meeting
283 SIVE, 181-184
- 284 3. Mari G, Rizzato G, Merlo B, Iacono E, Bucci D, Seren E, Tamanini C, Galeati G, Spinaci M. Quality
285 and fertilizing ability *in vivo* of sex-sorted stallion spermatozoa. Reproduction in Domestic Animal
286 2010, 45: 331-335
- 287 4. Samper JC, Morris LH, Plough TA The use of sex-sorted stallion semen in Embryo Transfer
288 programs J Eq Vet Sc 2012;32:387-389
- 289 5. Lindsey AC, Morris LH, Schenk JL, Graham JK, Bruemmer JE, Squires EL Hysteroscopic insemination
290 of low numbers of flow sorted fresh and frozen/thawed Stallion spermatozoa Eq Vet J
291 2002;34:128-132
- 292 6. Clulow JR, Buss H, Sieme H, Rodger JA, Caldwell-Smith AJ, Evans G, Rath DH, Morris LHA, Maxwell
293 WMC Field fertility of sex-sorted and non-sorted frozen-thawed stallion spermatozoa, An Reprod
294 Sc, 2008;108:287-297
- 295 7. Gibb Z, Grupen CG, Maxwell WMC, Morris LHA, Improvements in the fertility of cryopreserved,
296 sex-sorted stallion sperm after low-dose hysteroscopic insemination J Eq Vet Sc 2012;32:397-422
- 297 8. Colleoni S, Spinaci M, Duchi R, Merlo B, Tamanini C, Lazzari G, Mari G, Galli C ICSI of equine oocytes
298 with se-sorted frozen-thawed semen results in low cleavage rate but normal embryo
299 development and pregnancies, Reprod Fert Dev 2009,1, 268

- 300 9. Carnevale E, Graham JK, Suh TK, Stokes JE, Squires EL Foals produced after ICSI using frozen, sex-
301 sorted and refrozen sperm, *Reprod Fert Dev* 2009,1, 267
- 302 10. Varner DD The Ins and out of sperm management Part II Semen processing strategies for artificial
303 insemination programs, 2011, *Proceed AAEP Annual Resort Symposium*, 98-107.
- 304 11. Ecot P, Decuadro-Hansen G, Delhomme G, Vidament M. Evaluation of a cushioned centrifugation
305 technique for processing equine semen for freezing. *Anim Reprod Sci* 2005;89:245-248
- 306 12. Waite JA, Love Cc, Brinsko SP, Teague SR, Salazar Jr JL, Mancill SS, Varner DD. Factors impacting
307 equine sperm recovery rate and quality following cushioned centrifugation. *Theriogenology*
308 2008;70:704-714
- 309 13. Bliss SB, Voge JL, Hayden SR, Teague SR, Blanchard TL, Brinsko SP, Love CC, Varner DD. Effect of
310 sperm number and cushion volume during centrifugation on quality and recovery rate of stallion
311 sperm (abstract). *International Symposium on Equine Reproduction*, Lexington, Kentucky,
312 August, 2010, *Anim Reprod Sci* 121S:S220-221.
- 313 14. Meyers SA, Overstreet JW, Lui IK, Drobnis EZ Capacitation *in vitro* of stallion spermatozoa:
314 comparison of progesterone-induced acrosome reactions in fertile and subfertile males. *J Androl*
315 1995;16:47-54
- 316 15. Morrell JM Stallion sperm selection: past, present and future trends *J Eq Vet Sc* 2012;32:436-
317 440
- 318 16. Padilla AW and Foote RH. Extender and centrifugation effects on the motility patterns of slow-
319 cooled stallion spermatozoa. *J Anim Sci* 1991;69, 3308–3313
- 320 17. Johnson LA. Sex preselection in swine: altered sex ratios in offspring following surgical
321 insemination of flow sorted X- and Y bearing sperm. *Reprod Dom Anim* 1991;26:309-314.
- 322 18. Heitland AV Jasko DJ Squires EL Graham JK, Pickett BW and Hamilton C. Factors affecting motion
323 characteristic of frozen-thawed stallion spermatozoa. *Eq Vet J* 1996; 28 (1) 47-53

- 324 19. Love CC, Blanchard TL, Varner DD, Brinsko SP, Voge J, Bliss S, Sudderth K, Teague S, LaCaze K.
325 Effect of daily centrifugation and resuspension on the longevity of equine sperm quality following
326 cooled storage. *Theriogenology* 2012;77:1911-1917.
- 327 20 . Alvarenga MA, Papa F, Carmo MT, Kievitsbosch T, Castro Chaves MMA, Neto CR. Methods of
328 Concentrating Stallion Semen. *Journal of Equine Veterinary Science* 2012; 32:424-429
- 329 21. Loomis PR Advanced methods for handling and preparation of stallion semen. *Vet Clin North Am*
330 2006; 22: 663-676.
- 331 22. Len JA, Beenhan DP, Lyle SK, Eilts BE Cushioned versus noncushioned centrifugation:Sperm
332 recovery rate and integrity. *Theriogenology* 2013;80:648-653.
- 333 23. Edmond AJ, Brinsko SP, Love CC, Blanchard TL, Teague SR, Varner DD. Effect of centrifugational
334 fractionation protocols on quality and recovery rate of equine sperm. *Theriogenology* 2011; 77:
335 959-966
- 336 24. Barrier-Battut I, Bonnet C, Giraudo A, Dubois C, Caillaud M and Vidament M. Removal of seminal
337 plasma enhance membrane stability on fresh and cooled spermatozoa. *Reprod Dom An* 2013;
338 48: 64-71
- 339 25. Gibb Z, Morris LH, Maxwell WM, Grupen CG. Dimethyl formamide improves the postthaw
340 characteristics of sex-sorted and nonsorted stallion sperm. *Theriogenology* 2013;79(7):1027-33
- 341 26. Hoogewijs M, Morrell J, Van Soom A, Govaere J, Johannisson A, Pieper S, De Schawer C, De Kruif
342 A and De Viegler S. Sperm selection using single layer centrifugation prior to cryopreservation
343 increase thawed sperm quality in stallions. *Eq Vet J* 2011; 43, suppl 40: 35-41
- 344 27. Balao da Silva CM, Ortega Ferrusola C, Morillo Rodriguez A, Gallardo Bolaños JM, Plaza Dávila
345 M, Morrell JM, Rodriguez Martínez H, Tapia JA, Aparicio IM, Peña FJ. Sex sorting increases the
346 permeability of the membrane of stallion spermatozoa. *Anim Reprod Sci* 2013;138(3-4):241-51

- 347 28. Balao da Silva CM, Spinaci M, Bucci D, Giaretta E, Peña FJ, Mari G, Galeati G. Effect of sex sorting
348 on stallion spermatozoa: Heterologous oocyte binding, tyrosine phosphorylation and acrosome
349 reaction assay. *Anim Reprod Sci.* 2013;141(1-2):68-74
- 350 29. Bochenek M, Herjan T, Okulski A, Smorag Z. Sperm chromatin abnormalities after semen sexing
351 procedure - preliminary results. In: 18th Workshop of the International Equine Gamete Group;
352 2005 Sep 18-21. Kuhlungsborn, Germany: R & W Publications (Newmarket) Ltd; 2005. p. 13–4.
- 353 30. Boe-Hansen GB, Morris ID, Ersbøll AK, Greve T, Christensen P. DNA integrity in sexed bull sperm
354 assessed by neutral Comet assay and sperm chromatin structure assay. *Theriogenology*
355 2005;63(6):1789-802
- 356 31. Gosálvez J, Ramirez MA, López-Fernández C, Crespo F, Evans KM, Kjelland ME, Moreno JF. Sex-
357 sorted bovine spermatozoa and DNA damage: I. Static features. *Theriogenology* 2011;75(2):197-
358 205
- 359 32. Bench GS, Friz AM, Corzett MH, Morse DH, Balhorn R. DNA and total protamine masses in
360 individual sperm from fertile mammalian subjects. *Cytometry* 1996 ;23(4):263-71
- 361 33. Gardiner-Garden M.. Techniques for sorting X and Y spermatozoa may adversely affect histone-
362 associated regions in human spermatozoa. *Hum Reprod* 1999;14 (5):1403–1404
- 363 34. Gibb Z, Butler TJ, Morris LHA, Maxwell WMC, Grupen CG. Quercitine improves the post-thaw
364 characteristics of cryopreserved sorted and non-sorted stallion sperm. *Theriogenology* 2013: 79,
365 1001-1009

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Table 1. Effect of pre-sorting treatments, sorting procedure and freezing on total sperm motility (TM), percentage of viable acrosome intact spermatozoa (VAI) and on the percentage of spermatozoa with damaged DNA (DFI).
D- simple dilution; CC- cushion centrifugation; SLC- single layer colloid centrifugation.

Semen treatment	TM			VAI			DFI		
	Pre-sorting Treatment			Pre-sorting Treatment			Pre-sorting Treatment		
	SD	CC	SLC	SD	CC	SLC	SD	CC	SLC
Pre-freeze									
Unsorted	55.8 ± 15.2 ^a	53.6 ± 15.8 ^a	64.1 ± 10.2 ^a	65.0 ± 11.0 ^a	66.6 ± 10.9 ^a	72.3 ± 8.6 ^a	27.9 ± 8.7 ^a	28.0 ± 9.0 ^a	21.5 ± 6.6 ^a
Sorted	57.1 ± 15.2 ^a	51.5 ± 15.8 ^a	53.9 ± 17.4 ^a	76.0 ± 5.4 ^a	74.0 ± 6.7 ^a	73.4 ± 5.2 ^a	12.7 ± 8.4 ^b	10.0 ± 5.4 ^b	7.4 ± 4.3 ^b
Post-thaw									
Unsorted	16.7 ± 9.3 ^b	14.0 ± 8.5 ^b	15.2 ± 6.0 ^b	26.8 ± 9.9 ^b	20.0 ± 7.3 ^b	25.8 ± 7.6 ^b	32.9 ± 10.7 ^{aA}	28.1 ± 6.6 ^{aAB}	22.0 ± 6.4 ^{aB}
Sorted	7.2 ± 6.6 ^b	6.0 ± 5.9 ^b	6.1 ± 4.6 ^b	27.1 ± 12.7 ^b	25.8 ± 10.6 ^b	26.1 ± 11.6 ^b	25.5 ± 10.6 ^a	24.3 ± 9.1 ^a	17.0 ± 5.1 ^a

^{a,b} within columns superscripts are different (P<0.05)

^{A,B} within row superscripts are different (P<0.05) in DFI values.